ELECTRON MICROSCOPE

TYPE "EMB-4"

MI-12950-D

INSTRUCTIONS

Manufactured by

RCA Victor Division of Radio Corporation of America

Camden, N. J., U. S. A.

Printed in U. S. A.

IB-39006

WARNING

THE VOLTAGES EMPLOYED IN THIS EQUIPMENT ARE SUFFICIENTLY HIGH TO ENDANGER HUMAN LIFE AND EVERY REASONABLE PRECAUTION HAS BEEN OBSERVED IN DESIGN TO SAFEGUARD THE OPERATING PERSONNEL. AN IMPORTANT PART OF THE PROTECTIVE SYSTEM IS THE SERIES OF DOOR INTERLOCK SWITCHES AND ANY TAMPERING WITH THESE SWITCHES SHOULD BE PROHIBITED. THE POWER SHOULD BE REMOVED COMPLETELY BEFORE CHANGING TUBES OR MAKING INTERNAL ADJUSTMENTS.

FIRST AID IN CASE OF ELECTRIC SHOCK

1. PROTECT YOURSELF with dry insulating material.
2. BREAK THE CIRCUIT by opening the power switch or by pulling the victim free of the live conductor.

   DON'T TOUCH VICTIM WITH YOUR BARE HANDS until the circuit is broken.

(A)

(B)

(C)

3. LAY PATIENT ON STOMACH, one arm extended, the other arm bent at elbow. Turn face outward resting on hand or forearm.
4. REMOVE FALSE TEETH, TOBACCO OR GUM from patient's mouth.
5. KNEEL STRADDLING PATIENT'S THIGHS. See (A).
6. PLACE PALMS OF YOUR HANDS ON PATIENT'S BACK with little fingers just touching the lowest ribs.
7. WITH ARMS STRAIGHT, SWING FORWARD gradually bringing the weight of your body to bear upon the patient. See (B).
8. SWING BACKWARD IMMEDIATELY to relieve the pressure. See (C).
9. AFTER TWO SECONDS, SWING FORWARD AGAIN. Repeat twelve to fifteen times per minute.
10. WHILE ARTIFICIAL RESPIRATION IS CONTINUED, HAVE SOMEONE ELSE:
    (a) Loosen patient's clothing.
    (b) Send for doctor.
    (c) Keep patient warm.
11. IF PATIENT STOPS BREATHING, CONTINUE ARTIFICIAL RESPIRATION. Four hours or more may be required.
12. DO NOT GIVE LIQUIDS UNTIL PATIENT IS CONSCIOUS.

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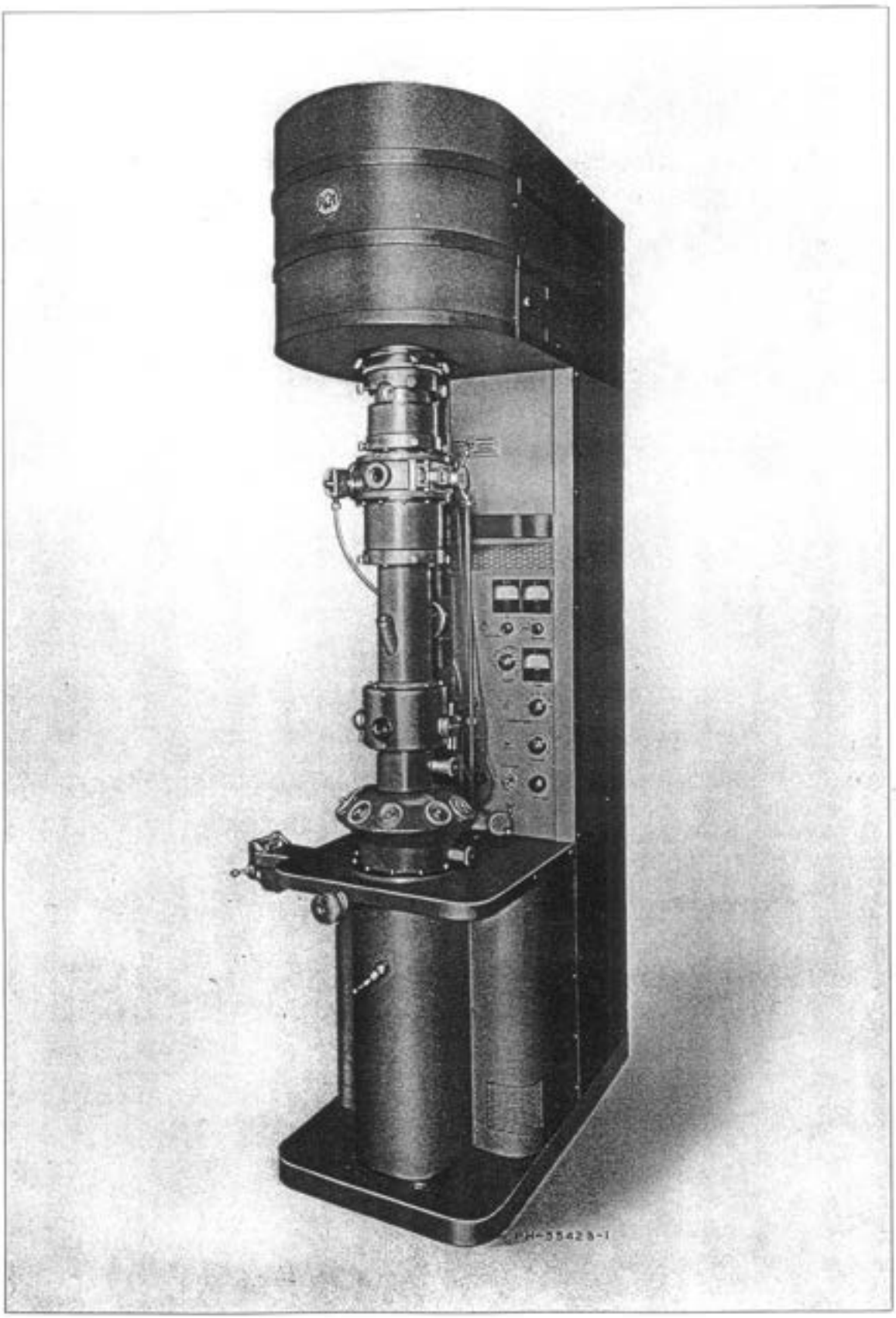

Figure 1—Electron Microscope, Type EMB-A, Front View

TECHNICAL SUMMARY

ELECTRICAL CHARACTERISTICS—

Electronic Magnification (21 steps) ..... 2500 to 25,000 diameters

Resolution ..... Better than 100 Angstrom Units

Anode Potential:

With respect to cathode (variable in 5-kv steps) ..... +30 to +60 kv

With respect to instrument proper (ground) ..... zero

Power Supply Requirements:

Line Rating ..... 120 volts, 60 cycles, single-phase

Power Consumption (maximum) ..... 3200 watts

TUBE COMPLEMENT—

	Type	Quantity	Circuit Number in Instruction Book	Class of Tube
1.	VR-105	6	V-24-27-36-48-49	Receiving
2.	VR-150	1	V-28	Receiving
3.	1616	2	V-1-2	Receiving
4.	56	1	V-44	Receiving
5.	5U4-G	6	V-3-4-6-7-9-10	Receiving
6.	5V4-G	2	V-5-8	Receiving
7.	5Y3-G	1	V-11	Receiving
8.	6L6	4	V-18-19-20-21	Receiving
9.	6L6-G	5	V-13-40-41-42-43	Receiving
10.	6SF5	3	V-29-31-45	Receiving
11.	6SJ5	2	V-38-46	Receiving
12.	6Y6-G	9	V-22-23-26-30-32-33-34-35-39	Receiving
13.	12SJ7	2	V-25-47	Receiving
14.	6V6-G	1	V-17	Receiving
15.	812	2	V-15-16	Power
16.	811	1	V-12	Power
17.	802	1	V-14	Power
18.	46602	2	V-52-53 (H. V. Rect. 6132)	Special
19.	47744	1	Thermo Gauge V-51	Special
20.	46601	1	Ion Gauge (C-787A) V-50	Special

Numbers 18, 19 and 20 are special tubes ordered by type number from Camden. Numbers 1 through 17 are standard tubes ordered through any tube dealer.

MECHANICAL SPECIFICATIONS—

Evacuation (maximum permissible pressure) ..... 0. 1 micron

Water Flow Requirement ..... ½ to 1 gallon per minute

Photographic Facilities:

Plate Size ..... 2 inches x 10 inches

Exposures per Plate ..... Up to 18

Overall Dimensions:	Microscope	Rotary Pumps (each)
Height	7 feet	16 inches
Width	21 inches	15 inches
Depth	37 inches	
Length		23 inches
Total Weight (net)	1287 pounds	117 pounds

EQUIPMENT

The Electron Microscope complete with all associated equipment is identified by the designation MI-12950-D. Each complete equipment as supplied consists of the following items:

Quantity	Item	Stock No.
1	Electron Microscope, Type "EMB-4"	MI-12955-D
2	Vacuum Pumps, Rotary Type	MI-12956-A
1	Set of Dry Batteries, comprising:	MI-12962
	12 45-volt "B" Batteries, Burgess No. A-30	
	3 22½-volt "B" Batteries, Burgess No. 4156	
	2 22½-volt "B" Batteries, Burgess No. 5156	
1	Set of Film Making Equipment	MI-12961
1	Accessory Kit	MI-12980-A
2	Instruction Books	IB-39006

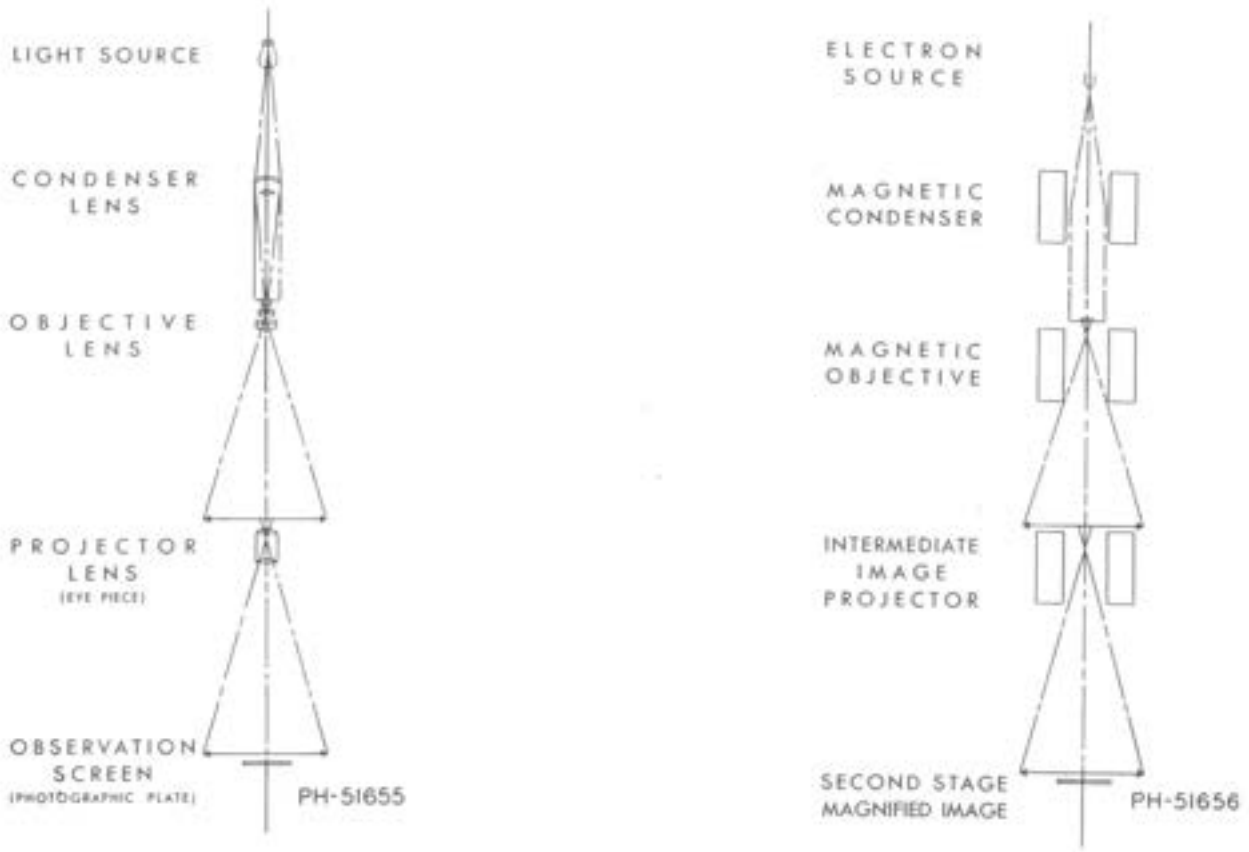

Figure 2—Analogy of Light and Electron Microscopes

INTRODUCTION

PHYSICAL CONSIDERATIONS — The basic principles of the Electron Microscope are in many respects analogous to those of the conventional light microscope. This similarity is illustrated in the drawing of Figure 2, which shows the essential elements of the light microscope at the left and of the electron microscope at the right.

Essentially, the light microscope consists of a light source, a condenser lens which controls the light on the specimen, a specimen stage which in the better grade of instrument incorporates means of moving the specimen in any direction in the plane of the stage, an objective lens which determines the ultimate quality of the image, and an eye-piece for visual observation of the image or a projector lens for micro-photography.

In the electron microscope, these elements are replaced by corresponding electronic elements. Thus, the light source becomes an electron source, and the solid light lenses are replaced by magnetic field lenses. Structural details, however, are quite different. Since electrons are absorbed and scattered by air, it is necessary to maintain a high vacuum throughout the entire electron path. The inherent nature of electrons, which makes a vacuum necessary, also requires a new type of specimen-mounting technique. Glass slides and cover glasses are eliminated and a much more "transparent" medium of support is employed.

Operation of the electron microscope is appreciably different from that of the light microscope and in many ways is much simpler and more convenient. Focusing of the electron beam is determined by the power of the objective and is therefore controlled simply by adjusting the current flowing through the objective coil, all distances remaining fixed. Similarly, no lenses need be changed to vary the magnification which is controlled by varying the strength of the current flowing through the projector coil.

As in the case of glass lenses in the light microscope, the electromagnetic lenses of the electron microscope are subject to such defects as aberration and diffraction. These are reduced through the use of a limiting aperture. The optimum diameter of this aperture is that for which the effects

of aberration and diffraction are equal. However, in actual practice, the opening differs from this optimum value to take into account the contrast and resolution desired with different types of specimens.

STABILITY CONDITIONS OF OPERATION—The effectiveness of a magnetic electron lens depends on the value of the current flowing through the exciting coil and on the velocity of the electron beam. In order, therefore, to obtain photographic records with all of the detail present in the electron image, it is imperative that the exciting current, and electron accelerating voltage remain extremely constant during the time of exposure. It is a function of the power supply circuits incorporated in the design of the RCA Electron Microscope to insure the required high degree of constancy of the energizing voltages and other operating conditions.

Disturbing factors of another nature must also be eliminated. These include the effects of varying external magnetic fields, of random electrostatic potentials accruing on partially insulating surfaces in the electron path, and of mechanical vibration due to external sources such as nearby heavy machinery, railroads and motor trucks.

Varying external magnetic fields will produce extraneous effects in the electron image but such effects have been minimized in the RCA Electron Microscope by adequate shielding of the sensitive regions. The presence of electrostatic potentials, however, constitutes a somewhat more difficult problem. It has been found that a partially carbonaceous, semi-conducting material is deposited on all of the diaphragms which are in the direct path of the electron beam. When these deposits become sufficiently heavy, the potentials at the exposed surfaces may be considerably different from that of the metal aperture. The effect is most serious in the case of the objective lens where the image defects thus introduced are sufficient to limit the resolution. At present, the simplest method of eliminating this difficulty is to replace the limiting aperture at periodic intervals. The resolution of the RCA Electron Microscope will vary from about 30 Angstrom units (equal to 30 x 10^{-7} millimeters), with a new aperture to about 100 Angstrom units at the end of one month of normal operation.

Little or no difficulty is to be expected from external mechanical vibration provided normal precautions are observed at installation. In the RCA Electron Microscope, independent displacement of any of the components of the magnification system are almost entirely overcome by rigid construction of the sensitive elements and by shock-mounting of the complete instrument.

SPECIMENS—The intensity distribution in an electron image formed by the microscope is, for the most part, due to variations in the scattering power of different parts of the specimen. In general, absorption of the electrons does not occur in the extremely thin type of specimens best suited for electron microscope observation. Such absorption actually is to be avoided since the energy released by the absorbed electrons appears as heat and may be sufficient to raise the temperature of the specimen to a point where decomposition and structural changes may occur. It has been found in practice that satisfactory images will be obtained with specimens up to one micron in thickness using electrons accelerated by potentials of the order of 60 kilovolts.

TYPE "EMD" DIFFRACTION UNIT—In order to further extend the field of applications of the Electron Microscope, a Diffraction Unit has been designed by means of which diffraction patterns may be obtained by either reflection or transmission methods. This Diffraction Unit is merely mentioned here for completeness, since it is described in detail in Instruction Book IB-39005.

DESCRIPTION

GENERAL LAYOUT OF THE ELECTRON MICROSCOPE—An overall view of the Type EMB-4 RCA Electron Microscope is shown in the photograph of Figure 1. An outline diagram of the assembly is given in Figure 3. Essentially the main body of the microscope consists of a vertical column about four feet high and six inches in diameter, made up of a number of sections which are bolted together. The joints are provided with air-tight rubber gaskets, and the required low pressure can be obtained within the column assembly. For this purpose, the column is connected to a diffusion pump, a rotary pump and an auxiliary pump through suitable manifolds as described later.

Mounted at the top of the microscope column is the electron gun assembly which comprises a cathode or source of electrons and an anode whose potential provides the proper acceleration and direction for these electrons.

Then, from top to bottom along the column, are located the magnetizing coil of the condenser lens with the condensing aperture and viewing screen, the specimen chamber, objective lens coil, intermediate tube, projector lens coil, lower viewing chamber and photographic chamber. Port holes are provided at suitable levels which allow examination of the image. Both the specimen chamber and photographic chamber are provided

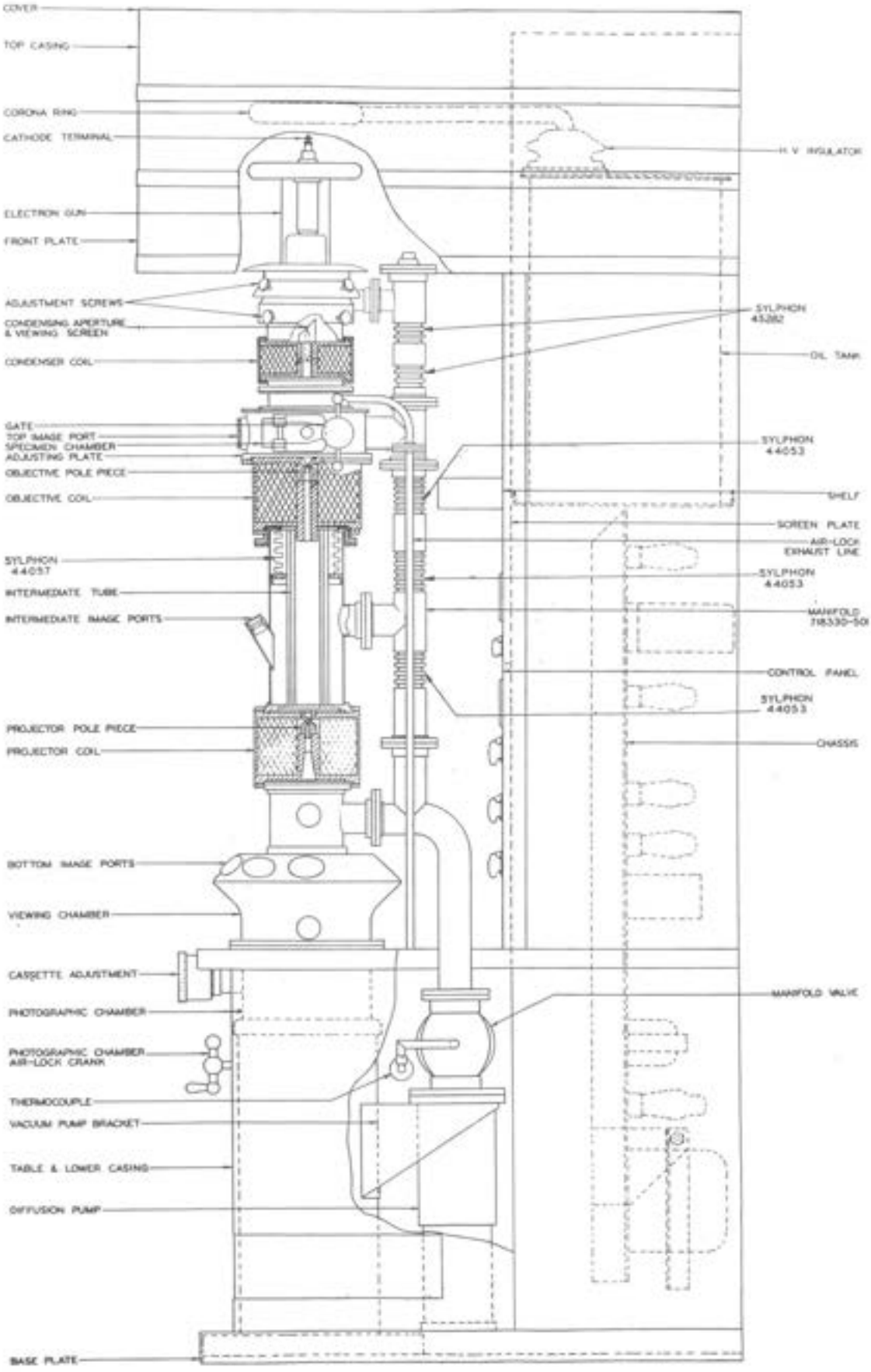

Figure 3—Electron Microscope, Outline Drawing

with gates and locks through which respectively specimens and photographic plates may be inserted into and removed from the apparatus without allowing atmospheric air pressure to reach the main body of the microscope column.

At the rear of the column assembly is a vertical cabinet which contains the necessary vacuum tubes, transformers and other circuit elements for the generation and accurate regulation of the supply voltages and currents which energize the electron gun and the three lens coils. Two electronic vacuum gauges are also provided, with their associated circuits, to indicate the pressure within the microscope. All operating controls are mounted on the front panel of the cabinet within easy reach of the operator. A description of these various component parts of the microscope is given in the following paragraphs. For ease of description these components have been grouped according to their respective functions, a thorough understanding of which will greatly facilitate the operation of the apparatus as a whole. These groups, as described in the following paragraphs, refer respectively to the magnification system, viewing and photographic facilities, vacuum system, electrical control and power system.

MAGNIFICATION SYSTEM—Under this title of "Magnification system" are included the following component units: (a) the electron source or electron gun assembly; (b) the condenser lens; (c) the objective lens; (d) the projector lens.

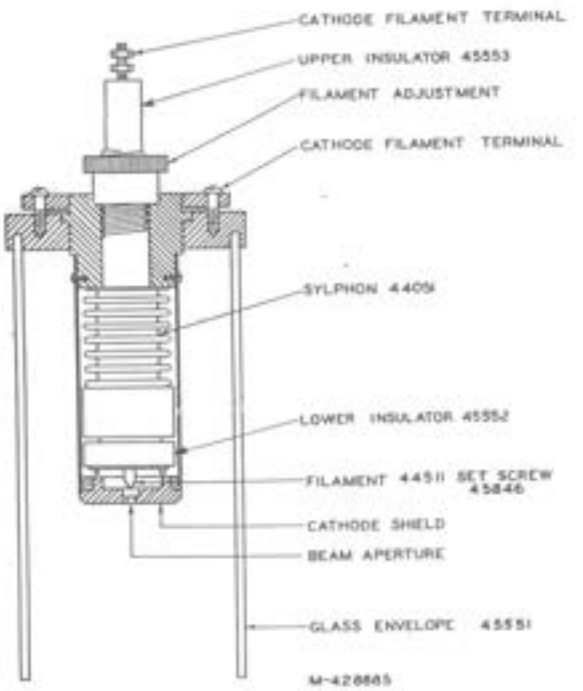

Figure 4—Electron Gun Assembly (M-428885—Sub. 1)

As stated in the preceding section, the microscope proper is built up of a number of separate units which are fastened together by means of specially constructed, mechanically rigid and vacuum-tight junctions. This sectional construction allows the easy replacement of separate parts in the case of failure. Synthetic rubber gaskets are used at all the demountable vacuum seals, while flexible metal bellows (sylphons) are used wherever motion must be transmitted to parts within the vacuum system. The vacuum seal between adjustable sections of the microscope is also maintained by means of sylphons.

Electron Source—The electron source or electron gun constitutes the top unit of the microscope, as shown in Figure 3, and contains the cathode and anode elements. The cathode is maintained at a negative potential with respect to the anode. The anode and entire instrument body are at ground potential. The negative cathode potential is adjustable within a range of from 30 to 60 kilovolts in steps of 5 kilovolts.

A drawing of the electron gun assembly is given in Figure 4. The electron gun includes the actual electron emitter (filament assembly Stock No. 44511) and its supporting and adjusting assembly. The filament assembly consists of a mica support and insulating disc, studs for supporting the actual filament, and studs to provide electrical connections. The filament itself is made up of 0.004" diameter tungsten wire, 0.5" long, bent in the form of a "V", with the free ends spot welded to the supporting studs. The radius of bending at the filament apex must be as small as possible, of the order of 0.005". The height of the filament apex with respect to the face of the mica disc should be close to 0.4".

The electron beam is constituted of electrons emitted from the apex of the "V"-shaped filament. These electrons first pass through a ⅛-in. aperture in the cathode shield and are then accelerated toward a ¼-in. aperture in the anode.

The electron gun may be raised or lowered along the vertical axis of the microscope by means of an adjustment thumb nut located at the top of the electron gun (see photograph of Figure 28). On the other hand, correct angular and lateral alignment of the electron beam with respect to the axis of the condenser lens is obtained by means of two adjustment blocks provided at the lower part of the electron gun, each having its own set of adjustment screws. For the purpose of description, the upper alignment block will be called the beam-direction adjustment block (and screws), while the lower alignment block will be designated as the beam-position adjustment block (and screws).

The beam-direction adjustment block is provided with a circular rim which rests on a spherical surface of the beam-position block. The spherical

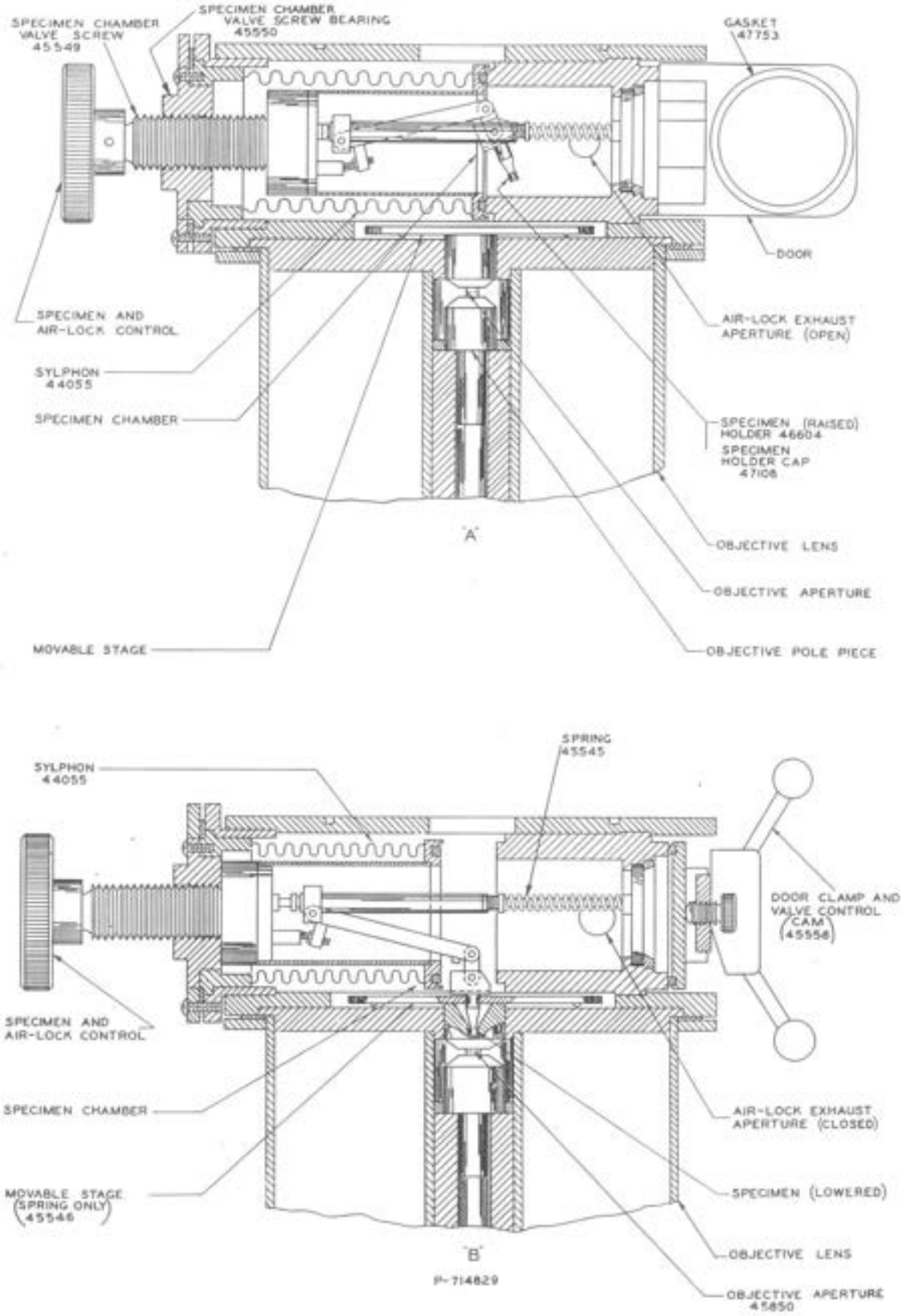

Figure 5—Specimen Chamber Mechanism (P-714829—Sub. 1)

surface is machined in such manner that the center of curvature coincides with the tip of the filament. The beam-direction adjustment screws permit the rim of the beam-direction block to slide along the spherical surface so that the direction of the electron gun may be varied without varying the position of the apex of the filament.

The beam-position adjustment block, on the other hand, rests on the plane surface of the condenser coil chamber. It may be displaced in a plane perpendicular to the axis of the microscope by means of the beam-position adjusting screws. The horizontal adjustment of the beam-position block carries the entire electron gun assembly with it as a unit. Therefore, after the electron beam has been aligned by means of the beam-direction adjusting screws so that it is parallel to the axis of the microscope it may be displaced by means of the beam-position adjusting screws so that it exactly coincides with the condensing aperture.

Condenser Lens—After leaving the electron gun, the beam enters the condenser lens. As described in the preceding paragraphs, a set of adjusting screws permits the condenser coil-electron gun system to be moved as a unit for the alignment of the lenses. The condenser lens is fitted with a limiting aperture. The current supply for it is in the electrical supply rack, with the control on the front panel, supplying current over a continuously variable range of from 20 to 120 milliamperes.

A port is provided through which a cross-section of the beam may be viewed to facilitate directing the beam into the condenser aperture.

Objective Lens—The objective lens consists of a coil which is completely encased in iron, with the exception of a gap located at the end of the central opening. The walls of this gap form a precisely machined receptacle for the pole-piece unit (see Figure 5). The pole-piece system of this objective is made in the form of a single plug which includes the pole-piece assembly and the limiting aperture with its support and centering adjustments. To align the axis of the objective and the illuminating system with the axis of the projector, an adjustment is provided immediately below the objective.

Projector Lens—The final image is formed from the portion of the intermediate image which passes through the projector lens aperture. The magnification of the intermediate image is about 100 diameters and the magnification by the projector lens can be varied between 25 and 250 diameters; therefore, the total magnification can be controlled over the range between 2500 and 25,000 diameters. The image is in focus for virtually all distances from the projector aperture to infinity.

VIEWING AND PHOTOGRAPHIC FACILITIES—The viewing and photographic facilities incorporated in the design of the Electron Microscope include the following components: (a) specimen chamber; (b) intermediate image viewing screen; (c) photographic chamber viewing screen; (d) photographic chamber. These are described in the following paragraphs.

Specimen Chamber—Immediately above the objective lens is the specimen chamber which contains the movable specimen stage and the specimen-changing mechanism, as shown in Figure 5. The latter consists of an air-lock system and associated vacuum valves which are so arranged that the specimen may be replaced quickly and simply without breaking the vacuum of the main chamber. The manipulation of one handle operates a lever system which lifts the specimen out of the specimen stage and places it in the air-lock chamber, at the same time as it closes the inside opening to that chamber, thus isolating it from the main vacuum system. The operation of unlatching and opening the outer door to the air lock chamber automatically operates the valves which break the vacuum in that chamber. The specimen may then be removed from the air-lock chamber and replaced by a new one and the reverse procedure followed.

A specimen chamber port is provided whereby the operator is able to observe the action of the specimen-changing mechanism during manipulation of the controls of that mechanism.

The intermediate ports and the beam-viewing port are made of lead glass. This protects the face and eyes of the operator against X-Rays that are produced by the high-voltage electronic bombardment.

The specimen itself is placed in a special specimen holder or cartridge which is held in a cradle within the specimen chamber. Two types of specimen holders are available. One holder (MI-12966) permits two ranges of instrumental magnifications. With a 60-kilovolt electron accelerating potential, the high range extends from about 3500 to 20,000 diameters, while the low range extends from 1000 to 4000 diameters. Another

type of holder (MI-12976) permits the preparation of stereo-micrographs, with a magnification of about one-half that obtained with the Specimen Holder MI-12966 when the specimen is in the "high" magnification position. Both holders, as well as the procedure for placing the specimen and inserting the holder into the cradle are described in greater detail in the Section of this Instruction Book devoted to the "Operation" of the equipment.

Intermediate Image Viewing Screen—Between the objective and projector lenses, are the intermediate tube and port for viewing the intermediate image. The image produced by the objective is observed on a fluorescent screen situated just above the projector. As this image is important for the alignment of the instrument, a port is provided through which the operator may observe the image.

Photographic Chamber Viewing Screen—Upon a large fluorescent screen in the final viewing chamber, the projector lens produces a magnified image of the selected portion of the specimen. The final image may be viewed through six observation ports in the walls of the viewing chamber placed to allow binocular vision for three observers.

Photographic Chamber—Photographic records are made by lifting the fluorescent screen and allowing the electron image to fall directly on the photographic plate which is placed immediately below, as shown in Figure 7. The 10" x 2" photographic plates which are used enable a number of images to be recorded on each, thus reducing the loading time per picture. They also allow series exposures to be taken with the focus changed slightly from exposure to exposure. In this way, the ultimate resolving power of the microscope may be exploited. The exposure times vary from one to several seconds, according to the specimen, the magnification, and the illumination intensity used. The size of the picture may be varied from 3" x 2" to ½" x 2", by means of a picture-limiting mechanism situated just above the viewing chamber.

After a full set of exposures has been taken, the plate is moved into a side chamber. The photo chamber main valve is to isolate the photographic chamber from the main body of the microscope, as shown in Figure 8. The door and cam valve mechanism for changing photographic plates is identical to that used on the specimen chamber for changing specimens. The photographic plate is enclosed in a cassette which is light tight to enable the instrument loading to be accomplished in a lighted laboratory.

When a new plate is introduced, the auxiliary pumping system is turned on by the operation of closing the door latch until a sufficiently low pressure is attained (in about two minutes). The cassette snaps into a carriage which runs in grooves in the walls of the photographic chamber, motion being imparted to it through a metal sylphon and a pinion which engages a long rack attached to its lower side. The cassette control knob

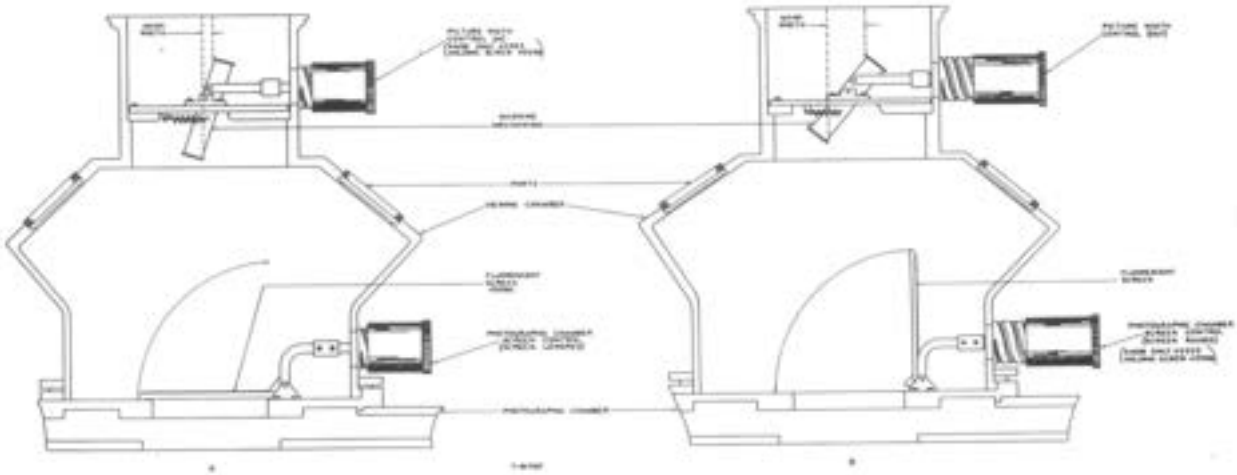

Figure 7—Picture Width and Screen Control Mechanism (T-617187—Sub. 1)

is calibrated to indicate the position of the plate, and in conjunction with the masking control, permits wide latitude in number and width of pictures per plate.

VACUUM SYSTEM—An electron beam, which takes the place of the light source in the Electron Microscope, requires a vacuum chamber for its existence and application. Figuratively, the RCA Electron Microscope is a cathode ray vacuum tube of large dimensions about four feet high and six inches in diameter and having but two main elements—a cathode or source of electrons and an anode whose potential supplies the proper acceleration and direction for those electrons.

Besides dissimilarily in size, the Electron Microscope differs from the ordinary vacuum tube in many other ways. The interior of the Electron Microscope must, of necessity, be exposed to atmosphere from time to time. On the other hand, an ordinary vacuum tube is permanently sealed, and thus, conditions are ideal for obtaining and maintaining very low pressures. Outgassing of the elements and interior walls through heat the use of "getters" (gas absorbers) and other processes tend to produce and maintain the excellent vacuum required by ordinary vacuum tubes for their applications.

The Electron Microscope has to be outgassed each time it is exposed to atmosphere, and the outgassing process becomes longer, the greater the exposure time. This is because the inner surfaces of the microscope absorb gases until saturation is reached and equilibrium is established with the surrounding atmosphere. Since it is not practical to employ continuous heating or "getters" to completely outgas and maintain vacuum in a system such as the Electron Microscope, another arrangement is employed—the use of high speed continuous pumping. While continuous high speed pumping will not produce low pressures equal to those obtained by heating and "getters", it will produce a pressure low enough to be entirely satisfactory for the establishment and use of an electron beam. In other words, the high speed pumping system removes gases at a faster continuous rate than the vacuum chamber can continually give them up, and in the process, produces the required vacuum.

The vacuum system of the Electron Microscope thus comprises (a) pumps for creating and maintaining the required vacuum within the microscope body or chamber, and (b) vacuum indicators or gauges which indicate when the internal pressure has reached a sufficiently low value to allow actual operation of the equipment. These are described in the following paragraphs. A general schematic layout of the entire vacuum system is given in Figure 9, which shows the pumps, valves and gauges with indication of their respective implied functions.

Pumps—As described in the preceding sections, the main body of the microscope constitutes, essentially, a large vacuum tube. It is, however, constructed in a number of sections joined together with rubber gaskets which form a vacuum seal. Furthermore, as the openings between some of the sections are extremely minute, a manifold is also incorporated in the design. This is essentially a long, flexible tube with separate connections to the main chambers of the microscope body. The larger volumes of the microscope can thus be pumped out very quickly through the manifold. This manifold is connected to an oil-diffusion pump. Incorporated in the diffusion pump is an aquastat which automatically disconnects the heater when an insufficiency in the water supply permits the condensing chamber to become overheated. The outlet of the diffusion pump is connected by means of a flexible rubber hose to a mechanical pump of the rotary type. The air-lock chambers are connected through a separate manifold of much smaller cross-section to a second rotary pump.

The two mechanical pumps are not described here further. They should preferably be installed in a sound-suppressor hood, as set forth in detail in the "Installation" section of the present Instruction Book (see page 35).

The oil diffusion pump is a 3-stage unit having two umbrella-type jets and one horizontal jet. Its pumping speed is about 200 liters per second with a 60 liter per minute mechanical pump acting as a fore-pump. The principles of operation of oil diffusion pumps are described in many standard textbooks (see for instance, Strong, "Procedures in Experimental Physics", Prentice-Hall, New York, 1938, pp. 111-120).

Vacuum Indicating Gauges—Since the vacuum system of the Electron Microscope goes, at various times, through cycles of atmospheric to operating pressure, it is necessary to employ suitable indicating systems so that instrument operation may commence as soon as the proper low pressure is attained.

Two visual pressure indicating systems are employed in the Electron Microscope. A thermocouple gauge acts as the detector for one system while the other employs an ionization gauge.

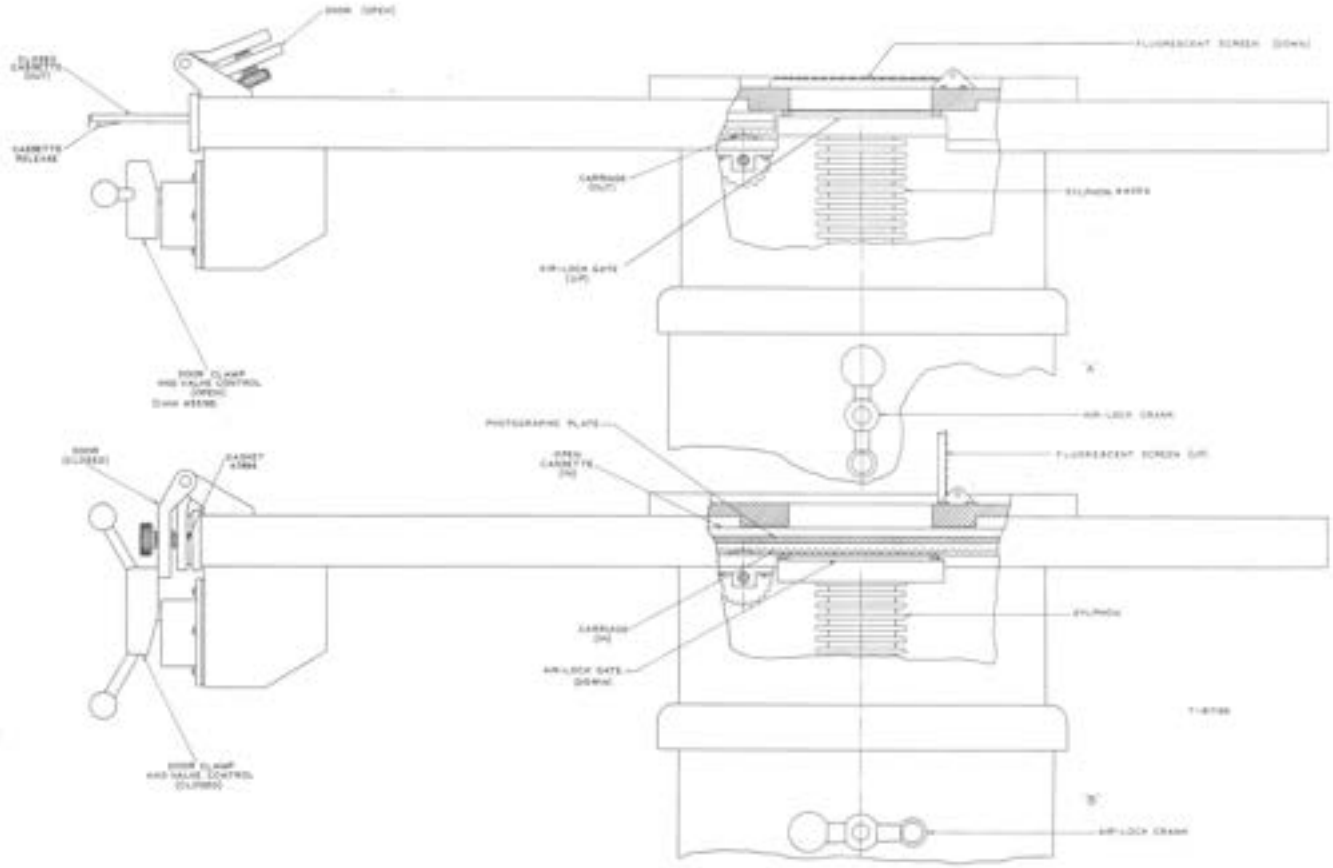

Figure 8.—Photographic Chamber Mechanism (T-61796—Sub. 1)

In ordinary usage of the microscope, the thermocouple gauge would be a sufficient indicator of the required low pressure. However, the ionization gauge is principally used as a check on the pressure during the later stages of pumping and is also used as an indicator of the pressure at any one given time during operations.

The **thermocouple gauge** simply contains a thermo-electric junction to which heat is applied by means of current. The thermo-electric current produced by heating the junction is measured by means of a galvanometer. Thus, as less and less gas surrounds the junction to carry away heat, more thermo-electric current is produced in the galvanometer. Correspondingly, **a rising galvanometer reading indicates decreasing pressure.**

The thermocouple gauge is used for a rough check of pressure and as a means for determining when the pressure in the microscope chamber is low enough to permit operation of the more sensitive ionization gauge. The thermocouple gauge is located near the oil diffusion pump and is connected so that it is between the pumps and the main valve of the Microscope vacuum chamber. In this location, the gauge can be used to check the condition and effectiveness of the pumps before the main valve is opened to allow exhaustion of the main chamber. After each closure of the main valve, it is good practice to use this feature of location and check galvanometer readings before opening the main valve. **A rising galvanometer reading is safe indication that the main valve may be opened.** This is a safeguard against a condition which might occur if the Microscope chamber were at a lower pressure than the pumps. Opening the main valve, under these conditions, permits pressure equilibrium to be obtained through the pump connections and may cause oil to be sucked from the pumps into the main chamber. Removing oil contamination as the result of such an occurrence, involves a laborious dismantling and cleaning operation.

Likewise, since it is possible for the thermocouple gauge galvanometer to indicate low pressures with the main valve in the closed position, it is good practice to check the position of the main valve before operating the ionization gauge. In other words, with the main valve closed, and with the galvanometer reading full scale, there is no proof that the pressure in the main chamber is sufficiently low for operation of the ionization gauge. To prevent accidental burn-out of the ionization gauge, the main valve should be checked for open position and the galvanometer should indicate full scale reading, before turning on the ionization gauge.

The **ionization gauge** is a conventional three-element vacuum tube whose elements are exposed to the gases of the Microscope chamber. The elements consist of a filament or source of electrons; a positively charged grid for accelerating and attracting the negative electrons; and a negatively charged plate which attracts positive ions.

In operation, electrons leave the filament and a number of them are attracted to, and impinge on the grid. However, a large quantity of the electrons miss the grid and arrive in the area between the grid and plate. Were it not for the repelling action of the negative plate, the momentum of the free electrons would carry them to the plate. The attracting force of the positive grid finally forces most of the electrons to return to the grid.

The electrons, in completing their orbit in the area between the grid and plate, collide with air molecules and produce positive ions. These positive ions are attracted by the negative plate and cause current to flow in the plate circuit. Thus, the larger the number of air molecules, the greater the number of collisions and the larger the ion current. Actually, **the amount of ion current, within the useful range of the gauge, is directly proportional to the pressure.**

The ionization gauge is located near the top of the Microscope chamber and in the vicinity of the electron gun. In this position, the pressure condition adjacent to the electron gun is checked most favorably. As stated before, the thermocouple gauge is the safety indicator for the ionization gauge. In like manner, the ionization gauge is the safety indicator for the electron gun.

The electrical circuits of the vacuum indicators are described on page 27, as "Block H" of the Electrical Control and Power System of the equipment.

ELECTRICAL CONTROL AND POWER SUPPLY SYSTEM—It is a function of the Power Supply system to provide, from the 120-volt 60-cycle supply line, the various alternating and continuous voltages required for the operation of the Electron Microscope and its associated instruments. At the same time, as explained on page 12 in the paragraph on "Stability Conditions of Operation," the system insures the necessary high degree of constancy of these operating voltages. It also embodies the adjustment and operating controls which may be required under actual conditions of use of the equipment.

The complete power supply is contained in a cabinet rack which is mounted behind the body of the microscope. The hood enclosing the upper part of the microscope fastens directly to the top of this rack and contains the high-voltage connection between the rectifier and the microscope. The connection consists of a polished one-inch tube with a corona shield over the microscope cathode; through this tube passes a flexible lead constituting one side of the electron microscope filament current circuit, the tube itself completing the circuit. The tube and corona shield are supported directly on the high-voltage bushing on the oil tank, which is mounted in the

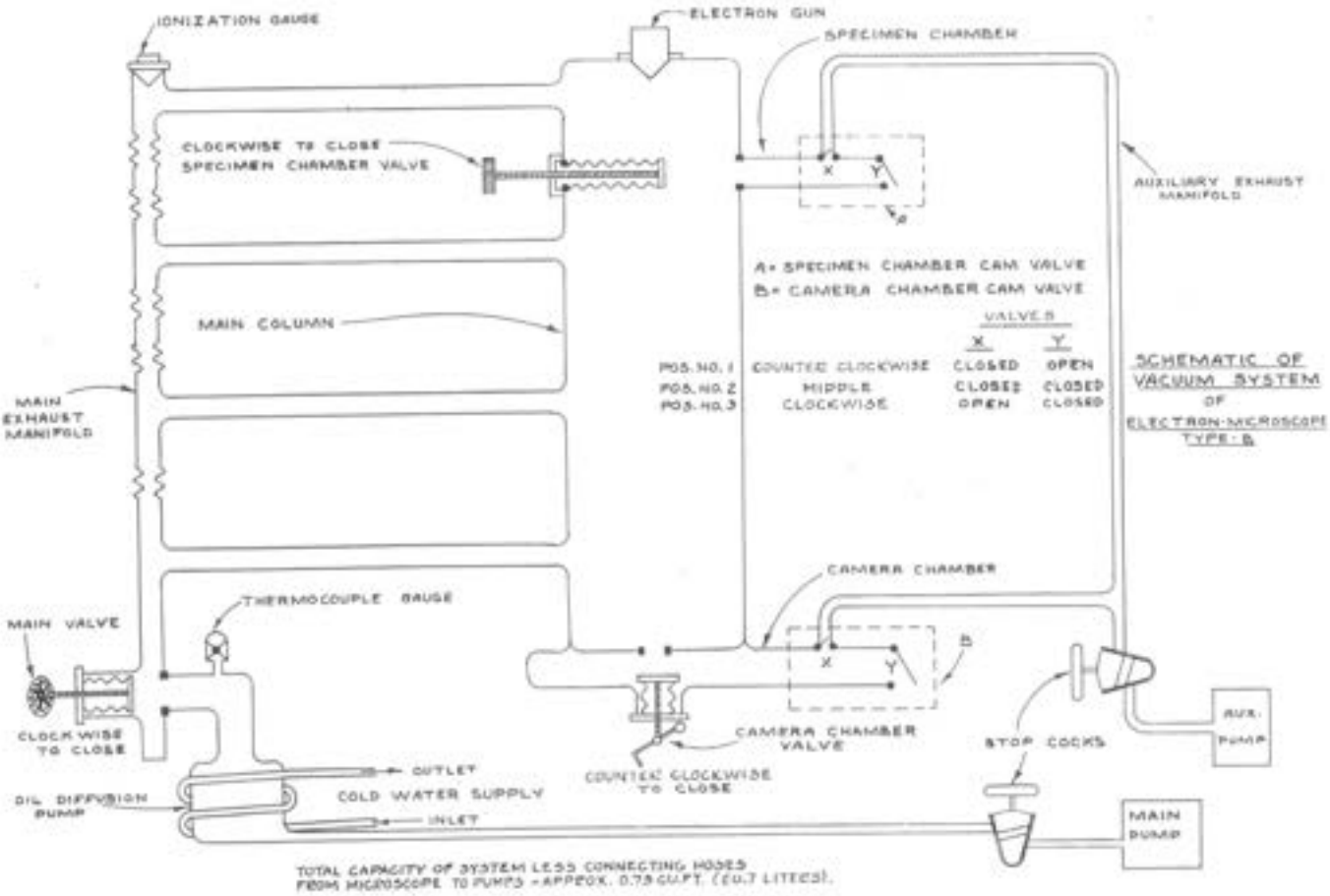

Figure 9—Vacuum System, Schematic Layout (PX-27624—Sub. 0)

top of the cabinet rack. The only physical connection to the microscope is through two flexible leads from the corona shield to the microscope cathode. This arrangement prevents mechanical vibration within the rack from reaching the microscope.

In front of the Power supply cabinet is mounted the Control Panel.

Both control panel and power supply unit are described in the paragraphs that follow.

Electrical Controls—Photographs of the control panel are given in Figures 24 and 25. The panel comprises all the power controls, controls for the vacuum indicating gauges, fuses, pilot lights, and associated indicating meter instruments.

a. **Power Controls**—The power controls mounted on the control panel are listed below.

1. "LIGHT"—The "LIGHT" switch (S3) provides for the illumination of the control panel by a fluorescent lamp under the shelf directly above the panel.

2. "POWER"—The main "POWER" switch (S2), when turned to the "ON" position, provides power to all the controls on the panel with the exception of those meters and controls that pertain to the vacuum system, and such power is indicated by the illumination of the **green** indicator entitled "MAIN POWER".

3. "HIGH VOLTAGE—The "HIGH VOLTAGE" switch (S4), when in the "ON" position, provides the power which supplies the accelerating voltage to the microscope cathode. This voltage is indicated by the **red** indicator entitled "HIGH VOLTAGE". The knob (S14) similarly marked "HIGH VOLTAGE" just to the right of the switch permits regulation of the voltage, and is calibrated in steps of five kilovolts from 30 to 60 kv. The "BEAM I" meter (M6), on the upper left side of the panel, indicates beam current (i. e., total current flowing between the cathode and anode or body of the microscope). A neon indicator or pilot light marked "OVERLOAD" will become illuminated should the high initial current necessary for charging the condenser of the high voltage filter system be sufficient to overload the driving system. The button marked "RELEASE" upon being pressed will release the overload safety relay, thereby causing the neon indicator to extinguish if the overload has cleared.

4. "CONDENSER" — The "CONDENSER" controls comprise a switch and control knob whereby the regulation of current into the condenser lens coil is made possible. The condenser current will be indicated by the lower right-hand "TEST" meter when the adjacent "RANGE" knob is turned to the "CON." position.

5. "OBJECTIVE"—The "OBJECTIVE" controls incorporate the switch and control knob; also the two controls entitled "OBJECTIVE FINE", and "OBJECTIVE VERNIER" which respectively permit fine and extremely fine adjustments of the objective lens current. This current may be read on the "TEST" meter by placing the adjacent "RANGE" knob in the "OBJ." position.

6. "PROJECTOR"—The "PROJECTOR" lens controls consist of a switch which turns on the current to the lens coil and a control knob for the regulation of the current. This current also is indicated by the "TEST" meter, when the "RANGE" knob is placed in the "PROJ." position.

7. Also appearing on the panel is an **amber** lamp entitled "DIFF. PUMP" which indicates that the diffusion pump heater is turned on.

b. **Vacuum Gauge Controls.**—The vacuum gauge controls and indicating meters are located along the upper part of the control panel.

1. "THERMOCOUPLE" — The "THERMOCOUPLE" gauge and controls comprise two meters, a switch and a heater control, all of which are used to indicate pressures as described on page 20.

2. "I. G." or IONIZATION GAUGE—The "I. G." controls comprise two meters, a switch, a zero control ("I. G. ZERO ADJ."), a filament control ("I. G. FIL."), and a meter range switch ("MICROAMPS"), all of which enable accurate indication of low pressures. It will, also, be recalled that the "I. G." may be used as a check on the "THERMOCOUPLE" gauge at any given time in the course of operation.

Power Supply System—An overall schematic diagram (W-302790) of the power supply system is is shown at the back of this book. A block diagram (PX-274678) is also given which follows closely the physical arrangement of the schematic diagram. In addition, a circuit diagram (W-302953) is included, which is arranged to facilitate servicing of the equipment. It is recommended that this latter diagram be pasted in the door of the cabinet, where it will be available when checking the circuits. Tube data, test and check voltages are given in tabular form in a later section of this book, relating to Service and Maintenance of the equipment.

The following paragraphs are devoted to a detailed description of the various electrical circuits of the power supply and control system. To facilitate the description, the components of the system are described in the order in which they are grouped in the various blocks shown in the block diagram. Reference should be made to this as well as to the schematic diagram. Once the functions of each block are understood, the operation of the circuit as a whole can be interpreted readily.

WARNING—Many of the voltages used throughout the circuits of the microscope are dangerous to life. Circuit checking and troube shooting should be accomplished by no less than two operators. Even though power has been turned off, certain capacitors in the circuits are capable of storing electrical energy for considerable periods of time, at voltages which are dangerous to life. Before touching any of these circuits, they should be grounded and discharged with a "grounding rod." The grounding rod must have a well-insulated handle. It must be grounded through a circuit which must be continuous and of low resistance. The grounding connector must be flexible to withstand usage. It should be exposed so that its continuity may be checked readily. In addition to grounding, it is accepted and good practice to test every circuit requiring examination with a voltmeter, before physical contact is made.

NOTE—As a general rule do not remove tubes from circuits which are in operation.

Block A:—Block A consists of transformer T3 and its associated circuits. It also includes transformers T4, T5, T6 and T8. This latter group of transformers supplies heater power as follows: T4 delivers 2.5 volts at 10 amps. to tubes V1 and 2; T5 delivers 6.3 volts at 8.9 amps. to tubes V14, V15 and V16; T6 delivers 6.3 volts at 4.9 amps. to tubes V12 and V13; T8 delivers 6.3 volts at 10.25 amps. to tubes V17, V18, V19, V20, V21, V22, V23, V26, V29, V30, V31, V38 and V46.

The secondary a-c voltage of transformer T3 is approximately 1400 volts R. M. S. This voltage is rectified by tubes V1 and V2. The rectified voltage, of approximately 1250 volts, is regulated by tubes V12, V13 and V14. After regulation, it appears as 900 volts d-c across the capacitor C5 and input circuit of the first regulating tube V14. The input (grid-cathode) circuit of V14 is also supplied with a reference standard of potential—an opposing negative bias of 350 volts obtained from Block C through resistor R8. Any increase of the load, constituted by the circuits of tubes V15 and V16 (Blocks K, L, M and R), tends to reduce the voltage across C5 and likewise across the voltage divider R7 connected in parallel with C5. The grid of V14 thereby becomes in effect less positive, and this, in turn, makes the anode of V14 more positive. (This operation, of course, depends for its accuracy and stability on the bias reference standard mentioned before.) When the anode of V14 becomes more positive, it likewise makes the grid of the gain stage V13 more positive. This causes the cathode of V13 to draw current through resistor R4 and to approach the potential of the anode of V13, and therefore to become more positive. The cathode of V13 in becoming more positive also causes the grid of V12 to become more positive, thus lowering the internal resistance of V12. Thus, the resistances of both V12 and V13 have been reduced, and this raises the current flow from the source of positive potential (midpoint of T4) through the load point of positive potential (midpoint of T6) through the load (circuit of V15 and V16 to ground, Blocks K and L). This increased current flow through the load tends to restore constant potential across C5, which forms the load terminus. In this manner, more current is supplied to the load as the load increases across C5, and constant potential is thus maintained across C5. Capacitor C4 by-passes the input network of V14 and allows a-c regulation of any changes appearing across the load.

Briefly, the tube V14 compares the voltage drop across R7 with the standard reference bias voltage, and translates the voltage changes caused by the load across R7, through the stages V13 and V12. These then operate as continuously variable resistors to maintain constant voltage across C5, or between the positive potential load point "U-U" and ground.

The circuit adjustments for Block A consist of slider taps on R7. When the full load current of approximately 160 m.a. of circuits V15, V16, etc., is being drawn from the output of Block A, the slider tap for the screen grid of V14 is set for 100 volts with the slider tap for the control grid set so that the potential across C5 measures 880 volts.

The main "POWER" switch S2 and 20-ampere fuses F2 and F3 which are located at the bottom center on the front panel control all a-c power to the microscope electronic circuits with the exception of Block H, the Vacuum Indicator Circuits. When the switch S2 is closed, the green pilot light A1 indicates power is "ON".

Block B:—Block B consists of transformer T9, tubes V3 and V4 and associated filter network. Tubes V3 and V4 rectify approximately 550 volts R. M. S. furnished by the transformer T9 and deliver approximately 600 volts d-c to Block N (plate voltage for tubes V18, V19, V20 and V21) and to Block P (screen grid voltage for tubes V22 and V23). The output voltage of Block B can be read on the control panel test meter in position "P. A. 1000 VOLTS".

With the "POWER" switch S2 closed, power will be supplied to Block B by the closing of the "HIGH VOLTAGE" toggle switch S4. The red pilot A2 lights up when this switch S4 is "ON". The switch S4 controls the power which produces the 60 kv accelerating voltage. An extra circuit on S4 completes a d-c circuit from the rectifier of Block D to Blocks N and P. This circuit includes also an interlock switch S5 (in the small door at the top of the cabinet) which must be closed to complete the d-c rectifier voltage supply circuit.

Block C:—Block C consists of transformer T10, tubes V5, V26, V27, V28 and V29 and related circuit components. The function of Block C

is to supply regulated negative bias potentials to circuits of Blocks A, F, G, P and Q. Block C also supplies approximately 6.3 volts at 1.8 amps. filament power for V42 and V43.

The transformer T10 supplies an a-c voltage of approximately 640 volts R. M. S. (total) which is rectified by tube V5. This rectified d-c voltage measures about 430 volts and is regulated by tubes V26, V27, V28 and V29. After regulation it appears across the terminals of R26, which also form the load terminals of the circuit. One side of R26 is grounded. The other side is at approximately −350 volts with respect to ground. The cathode of tube V29 is connected to this ungrounded end of R26 through regulator tubes V27, V28. The plate of tube V29 is maintained at a reference potential of about −100 volts by the voltage regulator tubes V36 and V37. The grid of V29 is connected to an intermediate tap on R26. Assuming then that the grid and cathode of V29 are originally at about the same negative potential with respect to ground when the ungrounded end of R26 is at −350 volts, suppose that the rectifier load is increased. This load being connected across R26, such an increase in load causes the voltage across R26 to drop. Both the grid and cathode of V29 will then become less negative, with respect to ground. However, the cathode of V29 being connected to the ungrounded end of R26 through the regulator tubes V27, V28, while the grid of V29 is connected directly to the intermediate tap on R26, the action of the regulator tubes V27, V28 is such that the grid will become more negative than the cathode with respect to ground for any decrease of the voltage supply from the value of −350 volts. The grid of V29 in becoming negative with respect to the cathode causes the anode of V29 to become more positive. This, in turn, makes the grid of V26 more positive, thereby decreasing the resistance of V26. As the resistance of V26 reduces, more current is fed to the load circuit and thus a constant voltage tends to be maintained across the load and the load terminus R26. Capacitor C31 by-passes a-c voltage to the grid of V29 and thus permits a-c regulation.

Briefly, about 430 volts is fed from V5 to the load terminus R26. In series with this voltage is V26, which operates as a continuously variable resistor to produce the required −350 volts across the load. V29 translates the load changes appearing across R26 to control the variable resistor tube V26. Plate voltage for tube V29 is obtained from Block D.

The circuit adjustments for Block C consist in setting the slider on R26 so that the voltage across R26 is approximately 350 volts. This voltage can be read on the control panel test meter in position "−REG."

Block D:—Block D consists of the transformer T11, tubes V6, V7, V32, V33, V34, V35, V36, V37, V38 and associated circuit components. Transformer T11, in addition to supplying plate and filament voltage to the rectifier tubes V6, V7, also supplies 6.3 volts at 5.0 amps. for the heaters of tubes V32, V33, V34 and V35.

Tubes V6 and V7 rectify approximately 575 R. M. S. volts a-c given by transformer T11. The rectified d-c voltage, approximately 650 volts, is regulated by tubes V32, V33, V34, V35, V36, V37 and V38. After regulation, this voltage appears as 400 volts across resistor R39 and condenser C38. Regulator tubes V36 and V37, connected in series with each other and with the 15,000-ohm resistor R40 are bridged across the regulated output voltage of 400 volts appearing across R39. Tube V37 supplies a constant reference potential of 105 volts for the cathode of the input stage of the regulator circuit V38. Tube V36 supplies a constant reference potential of 210 volts for the screen of V38. The control grid of V38 receives a potential of about 100 volts from a slider connection on R39. Thus, the grid of V38 is normally about five volts negative with respect to the cathode.

If the load (circuits of Blocks C, E, F, G, H, N and P) increases, this tends to reduce the voltage across R39 and the grid voltage of V38 is thereby lowered (made more negative with respect to the cathode). This reduces the anode current in V38 and causes the anode to become more positive with respect to the cathode. The cathode voltage, of course, remains constant, as given by the regulation of tube V37. The grids of the parallel-connected tubes V32, V33, V34 and V35 also go more positive, since they are connected to the anode of tube V38. The increased positive voltage on the grids of these tubes causes more current to flow in their respective anode-cathode circuits and through the load and load resistor R39. Thus, as the load across R39 increases, the operation of V38 lowers the resistance of the parallel-connected tubes V32, V33, V34 and V35. This causes more current to flow from the source of positive potential (cathodes of V6 and V7) through filter chokes L21, L22 and L23, through the continuously variable resistance tubes V32, V33, V34 and V35, through the load resistance and R39 to the source of negative potential or ground. Therefore, the voltage drop across the load tends to remain constant, irrespective of the load resistance variations.

Briefly, V38 compares the voltage drop across resistor R39 with the reference voltage supplied by tubes V36 and V37, and translates the voltage variations (caused by the load across R39) into corresponding resistance variations of tubes V32, V33, V34 and V35. These tubes being in series with the voltage source, the voltage across the load is thereby maintained at constant value.

Capacitor C37 by-passes a-c voltage to the grid of the input stage and permits a-c regulation for this circuit. Resistors R31 to R38 are decou-

pling resistors for the parallel-connected stages V32, V33, V34 and V35.

The circuit adjustment for Block D consists of setting tap on R39 so that voltage across R39 is 400 volts. This voltage can be read on the control panel test meter in position "+REG."

Block E:—Block E consists of transformer T12, tubes V8, V30, V31 and associated circuit components. Transformer T12 furnishes rectifier tube V8 with all its a-c power. The total secondary high voltage is approximately 360 volts R. M. S.

The rectified d-c voltage measures about 185 volts and is regulated by tubes V30 and V31. After regulation this voltage appears across R47, R48 and the heaters of tubes V47 and V25, which elements constitute the load circuit of the regulated supply.

The function of Block E is to regulate the heater temperature and electron emission of two tubes (V25 and V47) whose circuits are critical to such changes as line voltage variations. To accomplish this result, the regulator circuit tends to produce a constant voltage drop across the total load circuit of approximately 470 ohms, and thereby maintains a constant current of 150 m. a. through the heaters of V25 and V47.

The grid of the regulator tube V31 is connected through R45 to the ungrounded end of resistor R26 of Block C (which is at a voltage of −350 volts to ground). It is also connected, through R46, to some point of the load circuit, constituted by a tap on resistor R47. The grid bias voltage of V31 thus comprises the constant regulated voltage of −350 volts of Block C and the voltage drop across the tapped portion of R47, which latter voltage drop is a function of the load. If then the voltage drop across the entire load decreases, the potential at the tap of R47 decreases also and drives the grid of V31 to become more negative. This causes the anode of V31 to become more positive and, in turn, causes the grid of V30 to become more positive with respect to the cathode of V30. When the grid of V30 becomes more positive, more current is drawn from the source of positive potential (the cathode of V8) through the anode-cathode circuit of V30, through the load circuit, including V25 and V47 heaters, to the source of negative potential or ground. The anode of V31 (and also the grid of V30) obtains proper constant voltage of +400 volts from Block D. The cathode and screen of V30 obtain their proper potentials from the source voltage through resistors R42 and R43, respectively. The anode is connected directly to the source voltage. Capacitor C40 provides the low impedance path for a-c regulation in this circuit.

Briefly, V31 compares the voltage drop across the load circuit with the standard reference bias of Block C and translates variations in the load circuit through the variable resistor and gain stage V30, causing V30 to maintain constant current in the load circuit.

The circuit is adjusted by means of the slider on R47 so that the control panel test meter reads 150 m. a. in the "FIL. REG." position. The voltage across the heater of each of the tubes V25 and V47 can be measured with an external d-c voltmeter, and each of these voltages should be about 13 volts maximum.

Block F:—Block F consists of transformer T13, tubes V9, V40, V41, V46, associated circuit components and the projector lens coil. Transformer T13 supplies approximately 6.3 volts at 1.8 amps. for the heaters of tubes V40 and V41.

Transformer T13 supplies power to the rectifier tube V9. The total secondary a-c voltage is approximately 860 R. M. S. The rectified d-c voltage, approximately 400 volts, is regulated by V40, V41 and V46 and appears as a maximum of 120 volts across the load circuit consisting of R57, R58, R160 to R179 and the projector coil.

The voltage which regulates the projector lens current is traced through the following circuit: The source of positive voltage is the cathode of V9; the circuit then continues through the hum filter reactors L24 and L25; through the anode-cathode circuits of the parallel-connected regulator tubes V40 and V41 and through the projector lens coil in series with R160 to R178, R57 and R58 to the negative voltage source or ground. The function of this circuit is to accurately regulate the current flowing through the projector lens coil and to maintain this current at whatever value is selected by the setting of switch S11 and its associated resistors R160 to R178. Adjustment of S11 and R160 to R178 allows the current through the projector lens coil to be set to any value between the approximate limits of 20 to 120 m. a.

Assuming that the switch S11 has been set to deliver some arbitrary value of lens current, the operation of the regulating circuit may be described as follows.

The input tube V46 of the regulator obtains its anode voltage from the +400 regulated voltage supply Block D, through the anode load resistor R54. The screen voltage for V46 is obtained from some convenient point on the load voltage divider-junction of projector lens coil and resistor circuit S11.

The grid of V46 is made negative with respect to the cathode by means of the standard reference battery B1. However, the grid circuit is completed to the cathode by way of the circuit S11 and resistors R57 and R58. Thus, the voltage drop across the circuit S11 and resistors R57 and R58 bucks the voltage from the standard battery B1. The resultant bias on the grid of

V46 is then the algebraic sum of the voltages across B1 and part of the load circuit as described. Resistor R56 acts as load resistor for the input circuit of V46.

A change in the load circuit caused by an increase of the load or a decrease of the source voltage, will make the bias potential of V46 more negative. As the grid of V46 becomes more negative, the anode of V46 becomes more positive. This, in turn, causes the grids of V40 and V41 to become more positive. The anode-cathode resistances of V40 and V41 are lowered as the respective grids of these tubes become more positive. The lowered resistances cause more current to flow in the load circuit and therefore the voltage drop in the projector lens coil tends to remain constant. It will be noted that the cathodes of V40 and V41 are positive with respect to ground, as controlled by the voltage drop in the load circuit. The grids of V40 and V41 are brought to proper bias potential with respect to their cathodes by means of the standard −350 volt bias (Block C), the +400 volt standard (Block D) and the voltage from the divider network R53 and R55. Resistor R52 acts as a decoupling unit for the parallel-connected tubes V40 and V41. Proper potentials for the screen grids of V40 and V41 are obtained from the source voltage through R50 and R51. Capacitor C45 provides the low impedance path for a-c regulation.

Briefly, any changes from the chosen current value in the load circuit, which includes the projector lens coil, causes the input stage V46 to compare these changes with the reference battery B1 and to control the constantly variable resistor and gain stages V40 and V41, so as to maintain constant current in the projector lens and load circuit.

There are no adjustments for the projector lens current regulator circuit. However, the successful operation of the circuit depends on the standard battery B1 and the recommended voltage is 30 volts. This is obtained from taps on two standard 22½-volt dry cell blocks in series, using 12 volts from one battery and 18 volts from the other. As the standard battery B1 depreciates, the projector current decreases in proportion, causing a corresponding decrease in the magnification obtainable. Good practice calls for a replacement of the battery B1 about every 6 to 8 months.

The stability of the projector lens current regulator may be checked as follows:

a. Set S11 for maximum current (clockwise). Current is read on the control panel test meter in "PROJ." position.

b. Connect a potentiometer (approximately 200 ohms) across a 1½-volt dry cell. Ground the "plus" side of the cell. Connect the potentiometer rotor to one side of a vacuum tube voltmeter. Connect the other terminal of the vacuum tube voltmeter to the grid of V46 (RCA-6SJ7). The vacuum tube voltmeter should have a sensitivity of 0.1 volt full scale deflection.

c. Adjust the rotor arm of the potentiometer until the voltage difference between grid and rotor arm is about 0.05 volt.

d. The stability, which should be better than 0.068%, measured over a period of one minute is given by:

$$\frac{\text{Maximum variation in volts} \times 100}{\text{voltage of rotor to ground}}$$

e. Voltage of rotor arm to ground should be measured with the vacuum tube voltmeter.

The switch S10 in the primary circuit of T13 permits independent "ON-OFF" control of the projector lens circuit. If the main "POWER" switch (S2) of the microscope is closed, do not remove the projector coil from its circuit unless S10 is in the "OFF" position. Disconnecting the projector lens coil while the circuit is operating may damage the coil on account of inductive kickback, or may damage the regulator circuit.

Block G:—Block G consists of the transformer T14, tubes V10, V39, V45, condenser lens coil and associated components. Transformer T14 supplies approximately 6.3 volts at 1.55 amp. to the heater of V39 and V45.

The transformer T14 supplies the rectifier tube V10 with all of its a-c power. The total secondary high voltage is approximately 600 volts R. M. S. The rectified d-c voltage, approximately 300 volts, is regulated by tubes V39 and V45 and appears as a maximum of 135 volts across the load circuit consisting of R63, R64, R65 and the condenser coil.

The voltage which is used to regulate the condenser coil current is traced through the following circuit: The source of positive voltage is the cathode of V10; the circuit then continues through the filter reactor L26; through the anode-cathode circuit of regulator V39; through the load circuit comprising the condenser coil and resistors R63, R64 and R65 to the negative voltage source or ground.

The function of this circuit is to regulate accurately the current flowing through the condenser lens coil, at whatever value of current is chosen by the setting of the variable resistor R63. The circuit is arranged so that the setting of R63 can adjust the current through the condenser lens coil to any value within the approximate limits of 20 to 120 ma.

Assuming R63 has been set to deliver some arbitrary value of lens current, the operation of the regulating circuit is described as follows:

The input tube V45 of the regulator, obtains its anode voltage from the +400-volt regulated supply (Block D) through the anode load resistor R60. The grid of V45 is provided with a bias reference voltage from the −350 volt supply (Block C) through R61. However, the grid circuit is completed to cathode by way of part of the load circuit R63, R64 and R65. Thus the positive voltage drop across R63, R64 and R65 bucks the negative reference voltage. The resultant bias on the grid of V45 is then the algebraic sum of the two voltages. Resistor R62 serves as the load resistor for the input circuit of V45. Capacitor C48 provides a low impedance path for a-c regulation. A change in the load circuit caused by an increase in the load or a decrease of the source voltage will make the grid potential of V45 more negative. As the grid becomes more negative, its anode becomes more positive. This, in turn, causes the grid of V39 to become more positive. This more positive grid potential causes the anode-cathode resistance of V39 to decrease resulting in increased current flow in the load circuit. Thus, the voltage drop in the condenser coil and load circuit tends to be restored and to remain constant. The anode and cathode of V39 receive their voltages from the source voltage, the voltage to the screen being regulated by R59.

Briefly, any changes in the chosen current value in the load circuit, which includes the condenser lens coil, will cause the input stage tube V45 to compare these changes with the reference voltage (Block C) and to control the continuously variable resistor and gain stage V39, so as to maintain constant current in the condenser lens and load circuit.

There are no adjustments for the condenser lens current regulator. The condenser lens current is read on the control panel test meter when the test meter switch is in the "COND" position.

The stability of the condenser lens current regulator may be checked as follows:

a. Set R63 for maximum current (clockwise).

b. Connect a 200-ohm potentiometer across a 1½-volt dry cell with "plus" side of the cell grounded. Connect the potentiometer rotor to a vacuum tube voltmeter. Connect the other vacuum tube voltmeter terminal to the grid of V45 (RCA-6SF5).

c. Adjust the rotor arm of the potentiometer until the voltage difference between grid and rotor arm is about 0.05 volt.

d. The stability, which should be better than 0.1% measured over a period of one minute, is given by:

$$\frac{\text{Maximum variation in volts} \times 100}{\text{Voltage of rotor to ground}}$$

e. Voltage of rotor arm to ground should be measured with the vacuum tube voltmeter.

The switch S12 in the primary circuit of T14 permits independent "ON-OFF" control of the condenser lens circuit. If the main "POWER" switch (S2) of the microscope is closed, do not remove the condenser coil from its circuit unless S12 is in the "OFF" position. Disconnecting the condenser lens coil while the circuit is operating may damage the coil on account of inductive kickback, or may damage the regulator circuit.

Block H:—The function of the electronic circuits of this block is to operate the vacuum indicator circuits. As set forth on page 18, the equipment includes two vacuum indicators, namely, a thermocouple gauge and an ionization gauge. The circuits for these gauges are shown, respectively, at the center and at the left of the lower part of the schematic diagram W-302790, to which reference is made in the following description.

The thermocouple gauge circuit is energized by the transformer T17. The secondary a-c current from this transformer is rectified by a copper oxide unit and fed through a 20-ohm current adjusting resistor R76 and a 0-100 scale milliammeter M1 to the thermocouple gauge C784. About 50 to 60 milliamperes, indicated on meter M1 are taken from the above described circuit to heat the thermocouple junction of the gauge C784. The thermo-electric current generated by the junction increases as the air pressure decreases in the microscope chamber, and is indicated by the galvanometer M2. The thermocouple gauge circuit is calibrated by means of the ionization gauge, as described in a later paragraph.

The ionization gauge circuit consists of the three tubes V11 (5Y3G), V44 (56) and ionization gauge I. G. (C786). Tube V11 rectifies a-c power from T15 and supplies about 160 volts d-c to tubes V44 and C786. Tube V44 operates as a gain stage and as a substitute for direct microammeter readings of ion current in the plate circuit of the ionization gauge, C786. In operation, resistor R78 (connected in series with the primary of T16) is adjusted so that the meter M3 indicates an ionization gauge grid current of 5 milliamperes. The grid current which flows from the grid to heater and thence through the 5000-ohm resistor R75 to ground causes a 25-volt drop in resistor R75. This places the heater of the ionization gauge at a positive potential of about 25 volts to ground. It therefore causes the plate of the ionization gauge, which is effectively tied to ground, to be at a potential of −25 volts with respect to the heater, or electron source of the ionization gauge. Thus, the plate is 25 volts negative while the grid is 135 volts positive with respect to the heater.

Ion current developed in the plate circuit of the ionization gauge flows through resistor R71, R72 or R73, depending respectively on whether the switch S13 is in the 100, 10 or 1 microampere scale position. The voltage drop across resistor

R71, R72 or R73 is applied to the vacuum tube voltmeter circuit which consists of the tube V44, resistors R66, R67, R68, R69 and the 0-1.0 milliammeter M4. Thus, ion current of the ionization gauge is actually read in microamperes on the 0-1.0 milliammeter of the vacuum tube voltmeter. The calibration procedure for both vacuum indicators is given in a later paragraph, concerning the preliminary adjustments of the equipment.

Block J:—Block J includes tubes V42, V43, V47, the objective lens coil and associated circuit components. No a-c transformer or rectifier is required for this block. All of the d-c power, other than that obtained locally from standard reference battery B2, is supplied by the +400-volt supply, Block D.

The voltage which regulates the objective lens coil current is traced through the following circuit: The source of positive voltage (Block D) feeds the parallel-connected regulator tubes V42 and V43 through load resistor R79; tubes V42 and V43 are connected in series with the objective coil (shunted by resistors R116 and R117) and with resistors R94 and R85 to R93 in parallel with R180 and R96 to R115; through R95 to negative potential or ground. The function of this block is to regulate accurately the current flowing through the objective lens coil, at whatever value of current is chosen by the settings of S16, S17 or R117. The circuit is arranged so that the current in the objective coil can be adjusted to any desired value between the limits of 20 to 140 m. a. through suitable settings of S16, S17 and R117.

Assuming that S16, S17 or R117 have been set to deliver some arbitrary value of objective current, the regulating circuit functions as follows:

The input tube V47 of the regulator obtains its anode voltage from the +400-volt supply (Block D) through the load resistor R80. The screen grid of V47 obtains its positive potential from a convenient point in the load circuit (rotor arm of S16). The grid of V47 is made negative with respect to the cathode by means of the standard reference battery B2. However, the grid circuit is completed to the cathode by way of part of the load circuit, through S16 to ground. Thus, the positive potential drop through S16, S17, R180, R94 and R95 bucks the voltage from the standard battery B2, and the resultant grid bias is the algebraic sum of the voltages across B2 and part of the load circuit as described. Resistor R84 serves as the load resistor for the input circuit of V47.

A change in the load circuit caused by an increase of the load or a decrease of the source voltage will make the grid bias potential of V47 more negative. As the grid becomes more negative, the anode becomes more positive and, in turn, causes the grids of the parallel connected regulators V42 and V43 to become more positive. As a result, the resistances of V42 and V43 are lowered and more current flows in the load circuit. This tends to restore and maintain constant the current in the objective coil and load circuit. The anodes of V42 and V43 obtain positive potential from the +400-volt supply through load resistor R79. The screen grids obtain positive potential from the same source through their respective load resistors R81 and R82. Resistor R83 is a decoupling resistor for the parallel connected grids of V42 and V43. Resistor R80 is the load resistor for V47.

The d-c feedback or regulation circuit is traced from the cathodes of V42 and V43, through the objective coil and resistor network, through the network of S16, battery B2, resistor R84, grid of V47 and anode of V47 to grids of V42 and V43. Since the above resistor and lens coil circuits are of high impedance, a-c regulation is obtained through C67 which by-passes the d-c load circuit and feeds voltage changes appearing at the cathodes of V42, V43 directly to the grid of V47 for regulation.

Briefly, any changes from the chosen current value in the load circuit, which includes the objective lens coil, cause the input stage V47 to compare these changes with the reference voltage of battery B2, to control the constantly variable resistor and gain stages V42 and V43 and maintain constant current in the objective lens and load circuit.

There are no adjustments for the objective lens regulator circuit. However, the successful operation of the circuit depends on standard battery B2, and the recommended voltage is 67.5 volts. This is obtained from three standard 22.5-volt dry cell blocks in series. As the standard battery B2 depreciates, the objective current obtainable will decrease, or, in other words, higher control settings will be required to focus a given specimen plane. Good practice calls for replacement of the battery B2 about every 6 to 8 months.

The stability of the objective lens current regulation is checked as follows:

a. Set S16, S17 and R117 for maximum current (clockwise). Current is read on the control panel test meter in the "OBJ." position.

b. Connect a 200-ohm potentiometer across a 4.5-volt dry battery. Ground the "plus" side of battery. Connect the potentiometer rotor to one side of a vacuum tube voltmeter. Connect the other vacuum tube voltmeter terminal to the grid of V47 (RCA-12SJ7).

c. Adjust the rotor arm of potentiometer until the voltage difference between grid and rotor arm is about 0.05 volts.

d. The stability, which should be better than 0.0075% measured over a period of one minute, is given by:

$$\frac{\text{Maximum variation in volts} \times 100}{\text{Voltage of rotor to ground}}$$

e. Voltage of rotor arm to ground should be measured with the vacuum tube voltmeter.

The switch S18 in the heater circuit of V42 and V43 permits independent "ON-OFF" control of the objective lens circuit. If the main "POWER" switch S2 of the microscope is closed, do not remove the objective coil from its circuit unless S18 is in the "OFF" position. Disconnecting the objective lens coil while the circuit is operating may damage the coil on account of inductive kickback or may damage the regulator circuit.

Block K:—Block K consists of the oscillator tube V15, oscillator coil L15, plate choke L1 and associated circuit components.

Block A supplies 900 volts to the anode of V15 through R9 and L1. Resistor R9 serves as a convenient bridging point for the control panel test meter to read the plate current drawn by V15. The choke coil L1 provides a d-c path for the plate current but presents high impedance to the r-f appearing at the anode of the oscillator V15, which it prevents from feeding back into Block A.
The tube V15 is connected in a conventional Hartley type oscillator circuit where grid-anode coupling is obtained through the common inductance L15. The frequency of the oscillator is about 175 kc. The oscillator output voltage appears across L15. This high frequency voltage is fed to Block M through the coaxial cable P5 and is used to heat the filament of V53 in Block M by way of the hybrid transformer L3, L4, L10.

An adjustable resistance R10 provides self-bias for the grid of V15. Capacitor C6 permits closer grid anode coupling by providing a low impedance r-f path around the resistor R10. Capacitors C8 and C9 provide an extremely low impedance path to ground for any r-f appearing at the cathode and prevent the r-f from feeding back into the filament transformer T5. Capacitor C10 by-passes any r-f leaking through stray or distributed capacities of the anode feed circuit L1. Capacitor C7 blocks the d-c from L15 and provides r-f coupling to L15.

Circuit adjustment of Block K is made by moving the slider tap on resistor R10 until the plate current, as read on control panel test meter in the "REC" position, is between 70 and 80 ma. Further adjustment data appear in the description for Block M.

Block L:—Block L consists of the oscillator tube V16, coil L2, and associated circuit components.

Block A supplies approximately 900 volts to the anode of V16 by way of the divider network R158, R181, R182, through R157 and L2. Resistor R157 serves as a convenient bridging point for the control panel test meter to read the current drawn by V16. The choke coil L2 supplies a d-c path for plate current but presents high impedance to the r-f appearing at the anode of the oscillator V16 and prevents it from feeding back into Block A.

The tube V16 is connected in a conventional Hartley type oscillator circuit. Grid-anode coupling is obtained through the common inductance of the primary winding of T1 (located in Block M). The frequency of the oscillator is about 70 kc. The oscillator output voltage appears across the primary of T1. This high frequency voltage is fed to Block M through the cable P4 and is used to heat the filament of the electron gun by way of coupling transformer T1.

Resistors R158, R181 and R182 are bridged across the 900-volt supply from Block A. An adjustable tap on R158 permits proper voltage to be taken from the divider to supply the anode of V16. Resistor R11 provides self-bias for the grid of V16. Capacitor C21 permits closer grid anode coupling by providing a low impedance r-f path around resistor R11. Capacitors C19 and C20 provide an extremely low impedance path to ground for any r-f appearing at the cathode, and prevent r-f from feeding back into the filament transformer T5. Capacitor C18 by-passes any r-f leaking through stray or distributed capacities of the anode feed circuit L2. Capacitor C17 blocks d-c from T1 and provides r-f coupling to T1.

The movable tap on resistor R158 (controlled from the front panel) permits adjustment of the temperature of the electron gun filament by controlling the amplitude of oscillation of V16. The plate current drawn by V16, as read on control panel test meter in the "FIL." position, should vary between approximately 15 and 50 m. a. as the resistor R158 is adjusted from minimum to maximum positions.

Block M:—Block M includes the entire equipment of the high voltage oil tank. The tank includes rectifiers tubes V52 and V53, inductances L3, L4, L5, L6, L7, L8, L9, L10, L11, transformer T1 and associated circuit components.

The filament of V52 is energized from the secondary of transformer T7. Filament power, which can be measured across the filament and support terminals of V52 when the oil tank unit has been raised slightly, should measure about 6.75 R. M. S. volts. The filament voltage is adjusted by varying the resistor R12. Power to the transformer T7 and the filament of V52 is always "ON" when the main "POWER" switch S2 is closed. Cable P3 connects T7 to the filament of V52.

The filament of V53 is powered from the balanced transformer circuit L3, L4 and L10. Power for the balanced transformer is received from Block K by way of cable P5. Capacitor C11 serves to tune the primary of the balanced transformer and L15 to resonate at the desired frequency. The filament of V53 is always "ON"

when main "POWER" switch S2 is closed. Cable P2 serves to conduct power at approximately 32 kc from Block N to the series voltage resonant circuit comprising inductances L5, L6, L7, L8, L9 and condenser C12. The oscillation frequency of the resonant circuit is determined by the series inductances L5, L6, L7, L8, L9, capacitance C12 and the stray and distributed capacitances of the circuit. The peak voltage developed in this resonant circuit is about 30 kilovolts (60 kv peak to peak).

Assuming that the rectifier circuit is at zero potential throughout, a d-c voltage of approximately 60 kv is obtained, as explained below, across the load circuit, i. e., between the anode and cathode of the microscope:

A positive increase of the input voltage will cause V52 to conduct and V53 to open. Because of the low impedance of V52 at this time nearly the entire input voltage appears across C12.

A negative increase of the input voltage will cause V52 to open and V53 to conduct with the result that the charge on C12 will divide between C12 and C14, in inverse proportion to their capacities. Roughly, the voltage across C14 will be one-thirtieth of that across C12.

The next positive excursion of the input voltage opens V53 and again causes V52 to conduct so that C12 is recharged to the full value of the input voltage.

The next negative excursion opens V52, closes V53 and adds a voltage increment to the existing voltage on C14. The process continues, within the limitations of other parts of the circuit, until the voltage across the load (or C14) approaches the input voltage as a limit. Nothing further occurs until C15 becomes discharged in some manner.

The voltage across C14 thus builds up in a series of steps, and may be shown to reach a value of about 90% of the input voltage in approximately 3 milliseconds time. The above described rectifier circuit is commonly termed a voltage doubler. Its output voltage is equivalent to the peak-to-peak input voltage, in contrast to the output of ordinary half and full wave rectifier circuits, which deliver only one-half the impressed peak-to-peak voltage value. The type of voltage doubler employed here permits the output circuit to be grounded. Due to the characteristic incremental build-up of its output voltage, the circuit is sometimes known as a "stair" counter, in reference to the shape of its time-voltage curve.

The negative d-c potential of 60 kv appearing at the anode of V53 is applied to the cathode of the microscope through the divider resistor R49 by way of the protective resistor R13. Coil L11 and Capacitor C68 connected in parallel form a current resonant circuit or wave trap for any 32 kc ripple which may appear in the 60 kv output voltage. A spark gap LR across the wave trap protects capacitor C68 from possible voltage surges.

Capacitor C13 and resistor R14 are part of the regulating circuit which controls the constancy of the 60 kv d-c output voltage. The control circuit is coupled to the regulator Block P through cable P1. The control circuit is described under the circuit details for Block P. Operating the high voltage unit without the cable P1, i. e., without regulation, permits excessive rectifier voltage to arise, and will result in damage to tubes V52 and V53 and associated components.

Summarizing the above description, the circuit connections from Block M to the other component circuits are listed as follows:

Cable	Frequency (cycles)	Function
P1	DC	DC regulation circuit
P2	32,000	High voltage tank feed
P3	60	Filament excitation V52
P4	70,000	Input voltage for T1
P5	175,000	Filament excitation V53
(Fil.)	70,000	Filament excitation—electron gun

The output current of T1 (power for electron gun filament) may be checked as follows:

1. To filament terminals of electron gun supply (flexible leads at end of corona shield tube) connect, in series, a Weston model 425 R-F thermocouple meter and dummy filament.

2. Dummy filament can be constructed from a 10-inch length of 0.040" dia. nichrome wire. Filament should be bent in the form of a hairpin. The two arms of the hairpin should be equally long, and can be conveniently separated and mounted on a piece of Bakelite, fibre or other insulation.

3. With the circuit described above, the r-f meter should read between 1.0 and 4.0 amps., as the beam control on the front panel (R158 of Block L) is adjusted from minimum to maximum positions.

4. The high voltage is **not** used in the above tests.

The rectifier tubes V52 and V53 can be checked as follows:

1. Remove V52 and V53 from oil tank.

2. Connect filament of rectifier to be tested to load end of cable P3.

3. Connect anode of rectifier through 25 mil. d-c milliammeter to cathodes of V1 and V2. This will apply 1250 volts to the anode of tube under test. **Caution**—be careful of 1250 volt lead. Also, microscope high voltage should **not** be turned on.

4. Place short from junction of R15 and R16 to ground.

5. 25 mil. meter should read not less than 5 m. a. or more than 15 m. a. plate current.

6. Rectifiers whose plate current exceeds 25 m. a. are generally "soft" and are of no further use. Rectifiers whose plate current is below 5 m. a. can be put to further use by raising their filament temperature slightly to increase the electron emission. Methods for raising filament temperatures of V52 and V53 are given in the description of Block K and this block, respectively.

Block N:—This block includes tubes V17, V18, V19, V20, V21, transformer T2 and associated circuit components.

This block may be described as consisting of an oscillator tube V17 and amplifier stage including parallel-connected tubes V18, V19, V20 and V21. The screen grid and anode of V17 obtain voltage from the +400 voltage supply (Block D). The grid is returned to ground or cathode by way of the normally closed contacts of the overload relay included in Block Q. Bias voltage for V17 is obtained by cathode resistor R151 and capacitor C55.

The tube V17 is coupled to the amplifiers by means of capacitor C57. The output of the amplifiers is fed into the high voltage tank circuit of Block M. However, a small amount of the output of the amplifiers appears across R135 and is fed back to the input of transformer T2. Thus, the required conditions obtain for starting and sustaining oscillations in the oscillator and amplifier stages: when a small oscillation is started in the anode circuit of V17, it is fed back to the grid of this same tube by the amplifiers, with a 180-degree phase displacement, so that the oscillations rise quickly to the maximum amplitude allowed by the circuit and tube conditions.

As stated in the description of Block M, the frequency of the high voltage given by the proper oscillators is determined by the constants of the high voltage resonant tank circuit. It follows that the transformer T2 not only serves to provide the feedback coupling required for the generation of oscillations, but it also tends to lock V17 at an oscillation frequency equal to that set by the high voltage tank circuit. Consequently, the power-oscillator circuit, once started, is locked in step with the high voltage tank circuit frequency and will remain so until other conditions interfere.

The resistor R153 and capacitor C54 as well as resistor R152 serve to reduce and control the amplitude of the signal fed back into the grid of V17. Capacitors C15 and C56 by-pass r-f back to the cathode and prevent it from reaching the supply circuits. The choke coil L12 provides a d-c path for the anode voltage but presents high impedance to any r-f which may tend to leak into the power supply system. The plate current to V17 is read on the control panel test meter with the switch S15 in the "EXC" position. The plate current should be approximately 25 m. a.

The anodes of the amplifiers (V18, V19, V20, V21) receive power from Block B. The total current is read across resistor R134 by the control panel test meter with S15 in the "P. A." 500 m. a. position. The anode voltage is read on the test meter with the switch S15 in the position "P. A." 1000 v.

Resistors R136, R137, R138, R140, R141, R142, R143, R144, R145, R146, R147 and R148 decouple the parallel connected amplifiers and prevent the occurrence of spurious oscillations. The grids of the amplifiers are returned to the cathodes through the ground connection at the normally closed contacts of overload relay of Block Q. Bias for the amplifiers is obtained through the common grid load resistor R150, and the amount of bias is determined by the amplitude of the signal from V17. Capacitor C58 provides a low impedance cathode return for the grid circuit. The capacitor C60 and inductance coil L13 constitute a resonant trap which prevents the r-f in the anode circuit from feeding back into the power supply, and provide a suitable d-c anode feed circuit. The screen grids of the amplifier tubes are energized through the filter of the rectifier of Block D, which supplies to them a voltage of approximately 650 volts. The screen grids of the amplifiers serve to control the amplitude of the amplifier r-f output. The method of control is included in the description of the regulating amplifier, Block P.

Block P:—This block includes tubes V22, V23, V24, V25, battery B3 and associated circuit components.

The function of Block P is to control the 60-kv d-c accelerating voltage of the microscope. This is accomplished by comparing the accelerating voltage with the voltage of the standard reference battery B3, and translating changes in the accelerating voltage through the d-c amplifier V22, V23 and V25 to control the screen grid voltage of the amplifier oscillators. These, in turn, regulate the amplitude of the r-f signal used to produce the 60-kv accelerating voltage.

The anode of the input tube V25 of the d-c regulator is energized through the load resistor R123 from the +400-volt supply Block D. Block D also supplies the screen grid through the divider R121, R122. The bias for V25 is obtained from a voltage divider which is bridged from the negative end of the 60-kv supply to cathode or ground. The divider consists of the resistors R14, R119 and standard battery B3. The grid is connected to the divider at the junction of R14 and R119. This would make the grid negative by roughly 555 volts (the resistance ratio of R14 and R119 being 1000 to 10 megohms approximately), were it not for the opposing voltage of

550 volts from Battery B3. Battery B3 establishes a reference potential for the grid and brings the bias to an optimum negative operating value.

If the voltage of the 60-kv source should decrease, the effect at the grid of V25 would be a decrease in negative potential, i. e., the grid would become more positive. The anode of V25 then becomes more negative as the grid becomes more positive and this causes the grids of the d-c amplifier tubes V22 and V23 to become more negative. This last effect causes the anodes of V22 and V23 to become more positive and to carry the screens of the amplifier-oscillators of Block N to a similarly more positive potential. The positive voltage swing of the amplifier-oscillator screens produces increased amplitude of the r-f for high voltage rectification. This completes the d-c feedback high-voltage stabilization loop.

A-C correction in the feedback is obtained through capacitors C13 and C66, which divide the voltage to the input of the regulator roughly in the same proportion as resistors R14 and R119. Capacitor C63 provides low impedance a-c coupling between V25 and V22 and V23. Impedance networks R125, C62 and R192, C61 by-pass intermediate frequencies and prevent them from appearing in the amplifier-oscillator circuits.

The parallel connected amplifiers V22 and V23 are decoupled by resistor R128. The screen grids of V22 and V23 are kept at constant voltage by the regulator tube V24. The source voltage for the screen grids is obtained at the unregulated output of the rectifier filter of Block D. Resistor R154 also supplies screen grid voltage for the amplifier-oscillators V18, V19, V20 and V21.

Grid bias for V22 and V23 is set at proper operating potential value by opposing the −350-volt supply (Block C) to the anode voltage of V25 (+400-volt supply, Block D) through the divider network R123, R124 and R129.

The "HIGH VOLTAGE" switch S14 on the control panel determines the operating voltage value of the Battery B3. Turning the switch S14 in a clockwise direction increases the voltage value from B3, and makes the grid of V25 more positive, which results in a higher fixed value of the accelerating voltage. The relation of Battery B3 voltages to accelerating voltages is approximately as follows:

S14 Kilovolts	B3 Volts
30	275
35	320
40	365
45	415
50	460
55	505
60	550

As the switch S14 is turned clockwise, the readings of the control panel test meter (for the "P. A. 500 m. a." position) will closely follow the engraved inscriptions of the switch S14. Normal "P. A." currents are generally an indication of normal accelerating voltages. Another rough check of the accelerating voltage is the reading of the "Beam" current meter (M5) when the electron gun filament is "OFF" and the pressure in the microscope column is at an operating value. A "Beam" current of 50 to 60 microamperes then indicates an accelerating voltage of about 60 kilovolts.

Each of the voltage taps of the battery B3 to S14 is protected by a $\frac{1}{10}$ amp. fuse. A blown fuse in any position will be indicated by a complete loss of accelerating voltage at that position. Likewise, any defective battery in the series of 12 units making up the 550 volts will result in a complete loss of accelerating voltage. As a set of batteries grows old the effect will be a slight drop in accelerating potentials. Batteries B3 should be replaced about every six months.

Block Q:—Block Q consists of tubes V48, V49, meter M5, overload relay and associated circuit components.

The functions of this circuit are to measure the anode-cathode current of the microscope; to shut down the amplifier-oscillator circuit when the beam current exceeds a given amount; and to protect the electron gun in case of an arc discharge from the cathode to anode or to the column proper.

The d-c path to ground for the high voltage rectifier can be traced from the mid-point of transformer T7 (filament supply for V52) through resistors R15, R16, R17, meter M5, resistor R18 and overload relay shunted by R19 and R20 to ground. The meter M5, in its series position, reads the entire current drawn from the high voltage supply by the microscope.

Across the secondary winding the transformer T7, capacitors C22 and C23 filter r-f currents from the d-c ground path. The arrestor gap L-R provides a by-pass to ground for any high voltage surges fed back from V52.

Filter networks R16, C51 and R17, C52 by-pass voltage fluctuations around the meter M5. Further protection for the meter M5 is afforded by the tube V49, which functions whenever the voltage across its terminals reaches or exceeds about 130 volts. At this voltage, V48 ionizes, draws current and acts as a low resistance shunt around M5 and R16 and R17.

The overload relay is adjusted to operate on a value of current slightly in excess of one milliampere. Should the current in the winding exceed this amount, the relay operates and accomplishes the following functions through its S. P. D. T. contacts:

1. Removes grid return for oscillator V17 and stops tube from oscillating by substituting high bias of −350 volts from Block C.

2. Accomplishes the same as (1) above for amplifiers V18, V19, V20 and V21. This action, along with (1) above, cuts off the 60 kilovolt d-c supply.

3. Removes short-circuit on resistors R22 and neon lamp A3. A3 glows from d-c supplied by −350 supply.

4. Relay winding becomes locked in the energized position by −350 volt supply fed through normally closed push button S8 and resistor R21. Relay remains locked until push button S8 is operated.

Resistor network R19, R20 and R21 properly divides current in the relay winding in accord with the voltage source, the beam current or −350 volt supply. Capacitor C53 protects contacts of push button S8.

INSTALLATION

NOTE—High voltage apparatus in the electron microscope is contained within a tank filled with transformer oil. Checks should be made periodically to be certain that the tank is properly filled (to within 3/8" of the bottom surface of the cover when cold). The oil employed is inflammable and care should be exercised in handling to avoid spilling. In addition, checks should be made by the purchaser **before installation** and precautions taken to comply with local fire or electrical regulations.

The electron microscope is dismantled sectionally at the factory and shipped in a number of individual crates. In view of this, therefore, the following discussion on "INSTALLATION" should be read carefully before uncrating and assembling the instrument.

An overall installation layout of the equipment is given in Drawing P-717760 of Figure 52. This should be followed as closely as possible.

UNPACKING—In unpacking the microscope, a number of precautions should be observed. Such precautions are:

a. Excessive force with heavy instruments (i. e., hammers, crowbars, etc.) should be avoided.

b. After unpacking all parts, they should be carefully set in a place where there will be no danger of tipping or falling.

c. Avoid handling the fluorescent screens and sylphons.

ASSEMBLY OF ELECTRON MICROSCOPE—In the assembly of the electron microscope, an orderly sequence should be observed. The following method of installation should be consulted as a reference in the assembly of the instrument.

1. Locate the base plate on a reasonably level floor and conveniently near water and electrical outlets. The plate should be checked with a hand level. and shims should be inserted beneath the mounting cushions as required.

Note—In choosing a site for the microscope, requirements are that the instrument be situated so that the back faces a window. This arrangement allows a sufficient amount of natural light in the room. At the same time, the microscope cabinet acts as a light shield during the course of operation. However, it should preferably be possible to darken the room if required. The site should also be reasonably free of any externally-caused vibrations and, also, one that is not within a strong variable magnetic field. It will be found convenient to have a photographic dark room in the immediate vicinity of the room in which the microscope in installed.

2. Set the pedestal and diffusion pump on the base plate and bolt these securely in position.

3. Fill the diffusion pump with 115 cc of octoil (see page 58 of "MAINTENANCE" section for detailed procedure).

4. Attach the diffusion pump valve.

5. Set the microscope cabinet and chassis assembly in place on the base plate and bolt securely.

6. Place the photographic chamber on the pedestal, and fasten that chamber securely to the pedestal. Make sure that the photographic chamber is assembled strictly parallel to the control panel. This will insure proper alignment of the further assembly.

7. Insert photographic chamber viewing screen.

8. Set the main portion of the microscope column (from final viewing chamber to electron gun adjustment blocks), on the photographic chamber. again making certain that the gasket is properly centered before attempting to tighten the bolts.

Note—In view of the varying sizes of the gaskets, those responsible for the installation should make certain that each gasket fits accurately before bolting After having centered a gasket, the bolting should be done systematically, so that no bolt will be tightened before all other bolts have re-

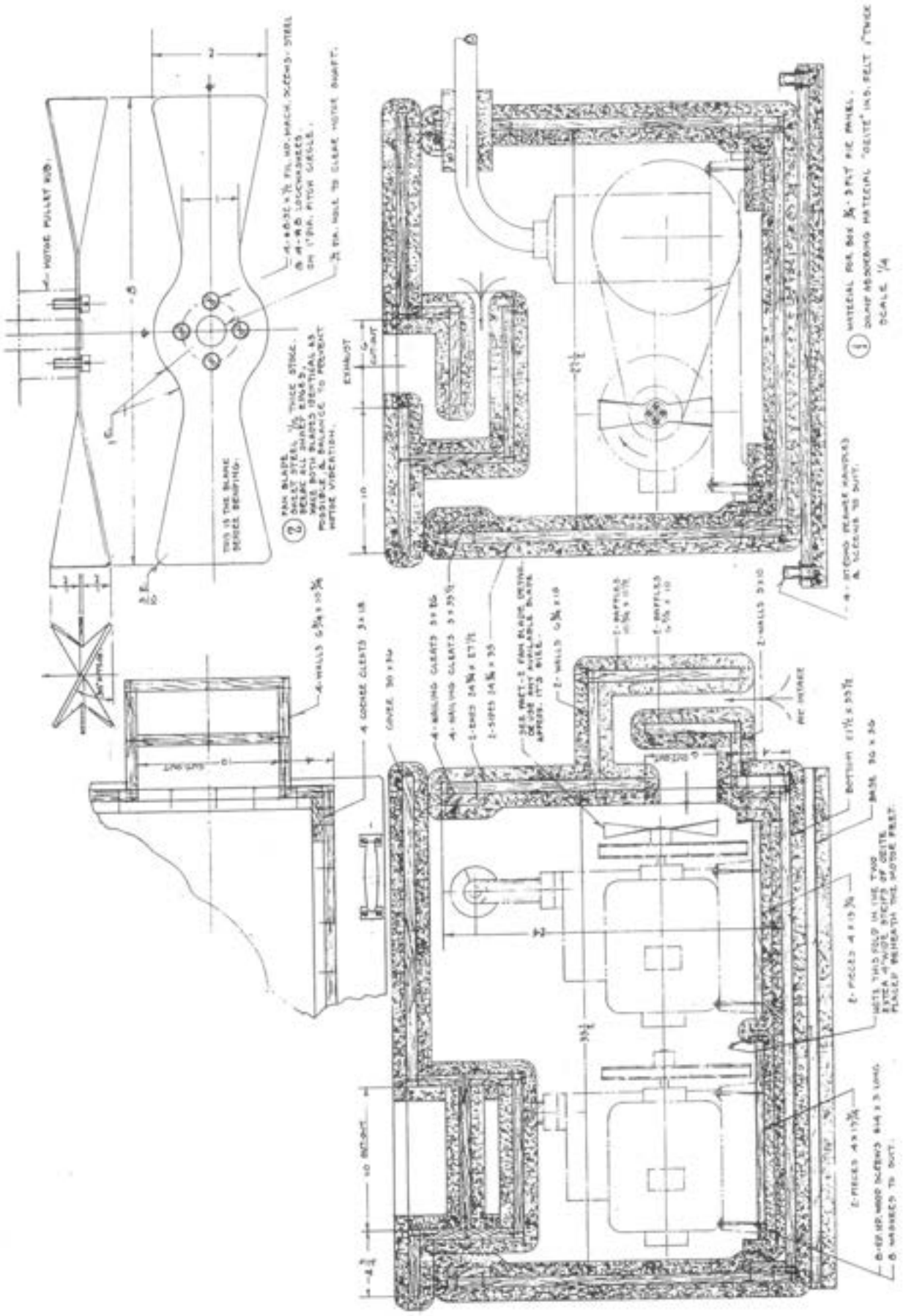

Figure 10—Noise Suppressor for Rotary Pumps (PX-275524—Sub. 0)

ceived an initial turn. This is best accomplished by turning one bolt a quarter of a turn and rotating around so that each bolt has received a similar turn, thereby, fastening all bolts at the same time

9. Open the microscope column immediately above projector lens.

10. Insert projector lens pole-piece (which must be absolutely clean) and intermediate screen.

11. Place the electron gun glass insulator over the anode assembly and carefully bolt the entire assembly to the beam-position adjustment block, again adjusting the gasket before tightening. (Make certain that the cathode and anode are absolutely free of dust and lint.)

12. Place the corona shields on the lower and upper portions of the electron gun assembly.

13. Set the three sections of the manifold into their respective positions, making certain that the gasket at each junction is properly centered before attempting to bolt these sections.

14. Insert specimen chamber mechanism.

15. Insert objective pole-piece assembly. Handle this with care and make certain that no dust or lint appears on any part of the assembly.

16. Raise the oil-tank assembly, preferably with block and tackle, and insert it into the top portion of the microscope cabinet.

17. Connect high tension leads from the oil-tank assembly to the chassis.

18. Connect leads from corona ring on the oil-tank assembly to the cathode terminal on the electron gun assembly.

19. Insert all tubes into their proper positions in the chassis.

20. Connect current cables to the condenser, objective and projector coils.

21. Insert "B" batteries into the panel under the right-hand side of the lower shield and check battery connections.

22. Insert the control panel lamp under the shelf directly above the control panel.

23. Insert the ionization gauge into the top of the manifold and connect to lead.

24. Attach thermocouple gauge (glass type) to copper pipe on main valve by means of Picein wax or equivalent. Thermocouple gauge (metal type) is fastened to the flange on the main valve by means of screws, gasket and sealing ring.

25. Attach canopy, chrome strips and skirt.

INSTALLATION OF ROTARY PUMPS—The preferred approximate location of the main and auxiliary rotary pumps is shown in the overall installation layout of Figure 52. The care to be given to the pumps before placing them in operation as well as during actual service is described in detail in the "MAINTENANCE" section of the present Instruction Book.

It is recommended that the pumps be installed in a soundproof housing. The housing detailed in Drawing PX-275524 of Figure 10 consists of a strong box built of ¾ thick 3-ply fir panels, or equivalent securely nailed together. It is equipped with a forced draft ventilation system utilizing one of the motors to which must be attached a fan blade such as detailed on the drawing. Any fan blade approximately the size shown may be used. The air inlet and outlet are labyrinth arrangements to prevent sound egress.

It will be noted that every bit of wood involved in the box construction is completely covered with one-inch thick "Ozite" felt insulation. Complete covering of the type shown is essential to successful operation. Most of the noise is absorbed by the "Ozite" layer covering the inside of the housing. Very little sound can reach the woodwork and thus cause it to resonate. What little sound does go through is almost completely absorbed by the outside layer of "Ozite."

The "Ozite" is held in place by one-inch long shingle nails. Staples may be used. Glue would be best since it would increase the damping action of the "Ozite" relative to the woodwork. However, gluing leads to apparent difficulties.

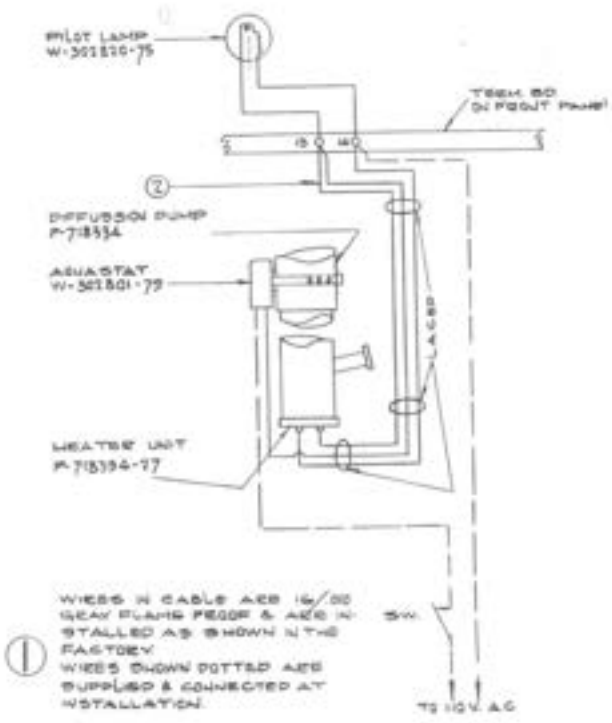

Figure 11—Diffusion Pump Aquastat and Heater Wiring Diagram (M-426534—Sub. 0)

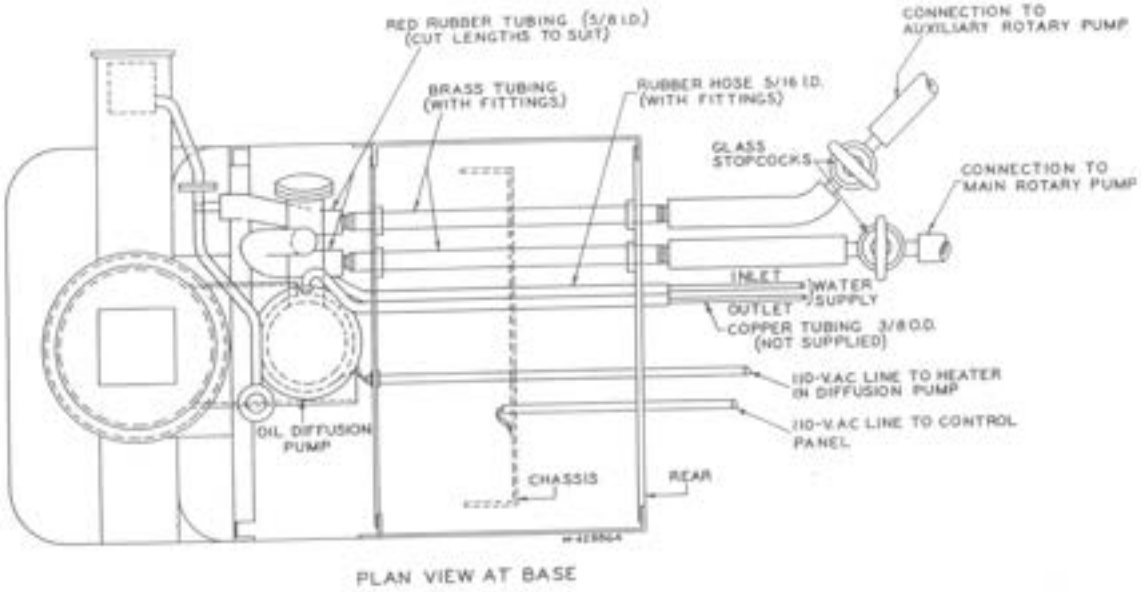

Figure 12—Water and Vacuum Lines, Installation (M-428864—Sub. 0)

The jointing of the various pieces of "Ozite" shown on the drawing is arbitrary. Continuous pieces are not necessary as long as the joints are pushed closely together. Certain joints may be improved by basting together, using ordinary string and a darning needle.

Use as few nails as possible, as each nailhead will transmit sound through the structure. The "Ozite" on the outside of the box is best secured by three or four bands of fairly heavy string passed completely around the box.

USE OF THREE-WAY STOP-COCKS with MI-12956A (Welsh Scientific Co.) Mechanical Pumps—The EMB-4 Microscope is equipped with two type 1405B Welsh Scientific Co., Duo-Seal Pumps. With these pumps are supplied two 3-way glass stop-cocks for sealing the lines from each pump. The 3-way stop-cocks are of the type which permits a main orifice to be connected to either of two pump leads or completely shut off. At installation, the mechanical pumps are connected to the main orifice and the Microscope pump lines are connected to either one of their two respective pump leads. Thus, the lines to the Microscope can be shut off or connected to the mechanical pumps as required. The remaining leads of each 3-way cock can be used to open either mechanical pump to atmospheric pressure (this arrangement assists pump starting after periods of idleness when starting against full load) or can be connected to other vacuum chambers, desiccators, etc., and used to evacuate these devices when the Microscope is not in use.

EXTERNAL CONNECTIONS—The external connections of the vacuum and water lines and of the electric cables depend on the particular conditions of each individual installation. Reference should be made to drawing P-717760 of Figure 52, as well as to the more detailed diagrams of Figures 11 and 12.

OPERATION

The operation of the electron microscope is simple after the fundamental concepts of design have become familiar. It is suggested for this reason that the operator should read the foregoing sections before attempting to operate the instrument. In the remainder of this section, the subject matter will be divided with respect to the three forms of technique involved in operation. These techniques pertain to the excitation of the instrument, the handling of specimens and the procurement of electron micrographs.

EXCITATION TECHNIQUE—WARNING—Operation of the electron microscope involves the use of high voltages which are dangerous to life. Do not change tubes or make adjustments inside the equipment with the high voltages "ON." Although an interlock switch is provided on the rear door of the cabinet, it is recommended, for added safety, to open the main switch in the supply line to the equipment if it is necessary to contact the circuits. Refer to safety warning on Page 23.

In energizing the electron microscope, there are three major factors to be considered and properly coordinated before electron images can be viewed or photographed. First, a vacuum of the order of 0.1 micron (10^{-4} mm of mercury) or better must be obtained in the large column of the microscope; second, the excitation voltages must be applied to the electron gun and field lens coils of the magnification system; and third, the electron beam must be correctly aligned with the microscope axis and focused to obtain the desired type of illumination.

Obtaining the Vacuum—The following procedure should be observed in evacuating the microscope column:

1. Throw all toggle switches on the control panel (particularly the "HIGH VOLTAGE" switch) to the "OFF" position and make certain that the rear door of the cabinet is closed so as to permit operation of the line interlock. If desired, the control panel may now be illuminated by throwing the "LIGHT" switch on the panel to the "ON" position.

2. Start the rotary pumps by closing the respective power switch installed for those units.

3. Make certain that the doors of the specimen and photographic chambers are closed and tightly clamped. Open the glass stop-cock on each rotary pump and the main valve on the oil-diffusion pump of the microscope.

4. Adjust the water supply to the diffusion pump so that there is a gentle flow of water through the cooling jacket. Then apply power to the pump heater by closing the external switch installed for that purpose. The amber "DIFF. PUMP" indicator lamp on the control panel should light upon connecting the pump heater and should remain lighted during normal operation. If the pump should become overheated due to insufficient water flow, the heater will be disconnected automatically by the aquastat in the pump and the lamp will cease to glow.

5. Connect the thermocouple gauge by throwing the "VAC. POWER" switch on the control panel to the "ON" position. Then adjust the "HEATER" control knob until the needle of the left-hand meter of the "THERMOCOUPLE" group is deflected to the value previously determined by calibration (refer to Page 38 for details of calibration procedure). The progress of the evacuation may now be observed on the adjacent or right-hand meter of the "THERMOCOUPLE" group. Normally, the needle of this meter will climb rather slowly until it reaches about "40" on the scale, then the diffusion pump will begin to take hold and the needle will climb rapidly thereafter to a maximum value. This maximum deflection should be reached within 15 minutes after the oil diffusion pump heater is connected and, when obtained, should be adjusted to exactly "100" on the scale by manipulation of the "HEATER" knob. The resulting heater current will hereafter be called the calibration value.

Note—Considerable variation in the calibration value is to be expected during the first few days after installation but the instrument will then settle down and maintain calibration fairly accurately. In normal operation, therefore, a satisfactory working vacuum is indicated by a reading of "100" on the right-hand meter with the left-hand meter adjusted to a calibration value of proven stability. No reading of the "I.G." should be attempted until the thermocouple has indicated a normal operating value.

6. Check the ultimate vacuum obtained, using the ionization gauge. To use this gauge, turn the "I.G. FIL." knob fully counterclockwise and then throw the adjacent toggle switch to the "ON" position. Adjust the filament current by turning the "I.G. FIL." knob clockwise until the left-hand meter of the "I.G." group indicates 2.5 milliamperes. The right-hand meter of this group should now be calibrated by turning the "MICROAMPS" knob to the "SHORT" position and adjusting the "I.G. ZERO ADJ." knob until the meter indicates exactly zero. Now turn the "MICROAMPS" knob to the "100" position and read the ionization current. An approximation to the actual pressure existing in the system may be obtained by using the equation

pressure in microns of mercury
$= 0.056 \times$ current in microamperes.

It should be appreciated that this calibration applies to air and is subject to considerable variation in practice because of the impurities (vapors and gases) which are pumped off the wall and gaskets of the vacuum system.

Experience has shown that pressures which produce an ionization current of 10 microamperes or less provide best operation although satisfactory results may be obtained up to 40 microamperes. With a tight and clean system, readings of from 5 to 12 microamperes can be obtained. Should the reading exceed 20 microamperes, the system must be checked for a leak by one of the methods described in the following section entitled "MAINTENANCE."

It should be noted that when first lighting the filament of the ionization gauge, a considerable amount of gas is discharged from the filament and plate of the gauge proper. This produces a high initial reading of ionization current which may be of the order of 50 to 60 microamperes. In normal operation, the current will decrease rather rapidly at first and more slowly later until it reaches a minimum value which indicates the true pressure in the microscope. Since the electron emission from tungsten varies considerably with changes in pressure, particularly at the rather poor vacuum indicated by an ionization current of 50 microamperes, it is necessary to readjust the emission current at intervals by means of the "I.G. FIL." knob until a stable reading of 2.5

milliamperes is obtained on the left-hand meter of the "I.G." group.

Upon approaching the ultimate vacuum, the ionization current will usually decrease to less than 10 microamperes. The meter range may then be decreased to 10 microamperes full scale for greater accuracy by turning the "MICROAMPS" knob to the "10" position. Once it has been established that the vacuum is satisfactory for operation, the ionization gauge should be turned off by throwing the "I.G. FIL." switch to the "OFF" position. The gauge should never be left connected on pressure readings in excess of 100 microamperes as such pressures will cause the filament to oxidize rapidly, thereby seriously reducing its life or burning it out. In routine operation, the ionization gauge need not be employed since the reading of the thermocouple gauge is usually sufficient.

When the electron microscope is to be left idle for an extended period, such as overnight, it is not necessary to keep the vacuum pumps in operation. The vacuum system, however, should first be sealed by tightly closing the main valve on the diffusion pump and making certain that the doors and internal gates of the specimen and photographic chambers are tightly clamped. Next, the glass stop-cock on each rotary pump should be closed after which the diffusion pump heater and the two rotary pumps may be shut down. It is usually advisable also to shut off the water supply to the diffusion pump. If the equipment is left under these conditions and there are no leaks in the microscope proper, fairly good vacuum will be maintained over a considerable period.

Vacuum Indicating Gauge Calibration — The ionization gauge is calibrated first and the procedure is as follows: With the power supply cord of the ionization gauge removed from its socket, but with the remainder of the circuit ready for operation, the "MICROAMPS" switch S13 on the control panel is placed in the "SHORT" position. The cathode slide contact of V44 on resistor R66 is set at a potential of about +8 volts to ground. With the slider of resistor R67 (I.G. ZERO ADJ." control on control panel) set at about mid-position, the other contact slider on resistor R66 is adjusted so that meter M4 (upper right-hand corner of control panel) reads zero current.

Next, the "MICROAMPS" switch S13 is placed in the "100" microampere tap position. Three-quarters of a volt d-c obtained from a one and one-half volt dry cell across a 200-ohm or higher resistance potentiometer is now impressed across resistor R71 with positive potential to the grid end of R71. With the three-quarters volt thus impressed across the input of the vacuum tube voltmeter, the cathode slider of V44 is adjusted so that milliammeter M4 reads exactly full scale. If the three-quarter volt is now applied successively to R72 and R73, the meter M4 should read full scale for the "10" and "1" microampere settings of S13 respectively, within the ±5 per cent tolerance limits of R72 and R73. The ionization gauge power cord can now be replaced, the three-quarter volt test battery removed, and the circuit is ready for operation.

The pressure within the Microscope column can be computed from the ionization gauge readings as follows with a current of 2.5 milliamperes flowing in the grid circuit:

Pressure in microns (or 10^{-3} mm of mercury) = 0.056 × ionization current in microamperes.

The readings will be accurate within ±10%. When a new ionization gauge is installed, a short time interval of operation should be allowed before readings are taken in order to allow the gauge to out-gas and settle to steady conditions. The same is true if the gauge is exposed to atmosphere for an appreciable period of time. Before each pressure observation, the "MICROAMPS" switch S13 is placed in the "SHORT" position, the "I.G. FIL." switch is left in the "OFF" position, and the meter M4 is balanced to zero reading, by means of the "I.G. ZERO ADJ." control. After balancing, the "I.G. FIL." may be turned on, the filament control resistor R78 advanced slowly until a grid current of 2.5 milliamperes is indicated and the ion current observed on the meter M3.

From time to time, the circuit conditions and tube V44 can be checked as follows:

With the "I.G. FIL." switch turned off, the meter M4 is balanced to zero with the switch S13 to the "100" microampere position. If there is a wide discrepancy in the zero readings, it is more than likely that V44 has become gassy or that electrical leakage is taking place around its socket. Replacing V44 will remove the trouble in most cases. The above described process can also be applied to the "10" microampere position of the switch S13. Zero discrepancies of this position should be slightly greater than in the "100" microampere check. For normal routine, zero balance is satisfactorily obtained by using the switch S13 in the "SHORT" position. For more accurate observations, especially with the 10 or 1 microampere scales, zero balance should be obtained with S13 on the corresponding tap, remembering, of course, to make all zero balances with the "I.G. FIL." in the "OFF" position.

The recommended safe upper limit of operating pressure for the ionization gauge C787A is one which produces not more than 90 microamperes in the meter M4. This corresponds to a pressure of about 5.0 microns. The life of the ionization gauge C787A may be prolonged considerably if the gauge is used only when required. **Never attempt to operate the ionization gauge unless the main valve is open and the thermocouple galvanometer reads full scale.**

Generally, the microscope high voltage and electron gun can be put into operation when the ionization gauge indicates a pressure of less than 50 microamperes (about 2.9 microns). A properly sealed average microscope chamber will indicate pressure of less than 10 microamperes (about 0.6 microns). It is well to note that the life of the electron gun filament will be prolonged also, by operating the filament at the lowest attainable pressure.

The thermocouple gauge, as stated previously, is used as a rough check of pressure. Adjustment and calibration of the thermocouple gauge circuit is made after the system under test has shown a pressure of less than about 2.0 microns (ionization gauge C787A reading of less than 50 microamperes) The "HEATER" resistor R76 on the control panel is adjusted so that the galvanometer M2 reads exactly 100. The current indicated by the milliammeter M1 is noted and this reading is used as reference for all future observations. In other words, the resistor R76 is always set to produce the reference current indication on the meter M1 and, at this setting, the galvanometer M2 will gradually reach its maximum as the pressure decreases. The full scale reading of 100 on the galvanometer represents the useful low pressure limit of the thermocouple. With the thermocouple circuit adjusted as described above, a reading of 90 on the galvanometer indicates a pressure of about 10 microns and a reading of 100 indicates about 2 microns. The current in the meter M1 will generally not vary more than ±5 milliamperes from 60 milliamperes in the calibrated condition.

As shown by the schematic diagram W-302790, the entire power input to the vacuum indicators is controlled by a switch S1 (marked "VAC. POWER" on the control panel), and protected by a 2-ampere renewable link fuse. Figure 24 shows the various parts of the vacuum indicator circuits which appear on the control panel. Engraved panel titles and schematic diagram nomenclature are cross-referenced to clarify the foregoing circuit description and adjustments.

Applying the Power—After a working vacuum has been obtained in the microscope (less than 50 microamperes on the ionization gauge), the next step is to apply the electrical power. It will be assumed for the purpose of discussion that a specimen and the photographic plate have been inserted in accordance with the specimen and photographic techniques subsequently described in this section. To energize the instrument and thereby produce an electron beam, proceed as follows:

1. Throw the main "POWER" switch to the "ON" position. The green "MAIN POWER" indicator lamp should light upon closing this switch and filament power is applied to the drivers for the high-tension and microscope filament supply. Ordinarily these tubes require about one minute to reach an operating temperature and the warm-up process may be observed on the lower right-hand ("TEST") meter by turning the adjacent "RANGE" switch to the "RECT." position. The meter deflection will normally increase almost to full scale and then after a short period will decrease rather sharply to the value, indicated in the tabulation of "Normal Meter Readings" printed at the end of the present section (see Page 47).

2. Shift the meter "RANGE" switch to the "PA" position and throw the "HIGH VOLTAGE" switch to "ON." Again observing the lower right-hand "TEST" meter, it will be noted that with the high voltage "ON" the needle deflection increases rapidly to a scale reading of about "100" and then decreases rather sharply to about "60" for 60 kilovolt accelerating voltage. This operation applies the high voltage to the cathode of the microscope, and the high voltage required for operation may be adjusted by means of the "HIGH VOLTAGE" control knob. The meter reading will vary depending on the selected value of high potential.

Note—The high initial current necessary for charging the condenser of the filter system in the high-tension unit is sometimes sufficient to overload the driving system and thus actuate the safety relay. This will be indicated by the sudden glow appearing in the neon indicating tube and by the "TEST" meter in "PA" position dropping sharply to zero. In this case, the "RELEASE" button should be pushed sharply. The meter should immediately read about "60." The indicating lamp should, thereupon, become extinguished. In the event that the meter stays at zero, and the lamp remains lit upon pushing the "RELEASE" button, the vacuum gauges should be checked, as also the surface of the glass insulator in the electron gun system (after having shut the power off). Other possible causes of repeated overloading in the high-tension system will be discussed in the section on "MAINTENANCE." Refer also to page 56 for a description of the adjustment procedure of the overload relay.

Alignment of Electron Beam—The following description applies to a step-by-step procedure for aligning the microscope column to obtain proper visual images. It is presumed, of course, that all parts of the instrument have been thoroughly cleaned and adjusted, as set forth in a later section. Alignment is accomplished by means of the adjustment screws and blocks described in page 14 at the end of paragraph entitled "Electron Source."

1. **Filament Focusing (Coarse)**—The action is observed at the filament focusing screen. Condenser, objective and projector lens settings are arbitrary. Specimen holder and objective aperture are not used.

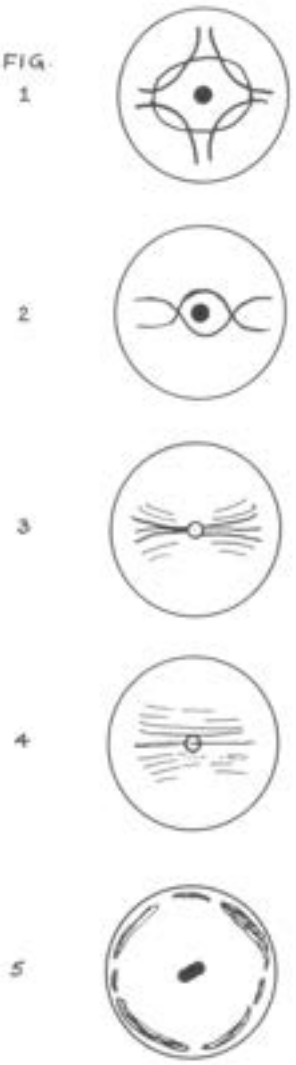

Figure 13—*Electron Gun Filament Images* (*KX*-387581—*Sub.* 0)

Lower the electron gun by means of the adjustable thumb nut at center of corona ring. For some low position of the gun filament a four cusped hypocyloid (astroid) will appear as shown in (1) of Drawing KX-387581 (Figure 13). The rotational position of the astroid is arbitrary.

Raise the electron gun. The filament image will go through the sequences 2, 3 and 4 as shown on the drawing. At the required gun height, the astroid form disappears and the image is blurred. **Caution:** Access to the electron gun is obtained through the small door in the upper housing. Opening of this door operates a protective interlock switch. However, as an additional precaution it is good practice, before raising or lowering the electron gun, to shut off the high voltage power supply, since this is dangerous to life. The tilting screws of the electron gun now are adjusted to permit the filament image to disappear in the filament focusing screen aperture.

2. Obtaining The Beam — The action is observed at the intermediate screen. The condenser lens current is set to some high value. The objective current is adjusted to approximately 115 ma. The projector current setting is arbitrary. Specimen holder and objective aperture are not used.

The condenser lens is approximately centered mechanically by eye. The electron gun is moved transversely until illumination is obtained on the intermediate screen.

3. Filament Focusing (Fine)—The action is observed on the intermediate screen. The condenser, objective and projector lens currents are set as in the preceding step (2). Specimen holder and objective aperture are not used.

The condenser lens current is reduced slowly from a high value until the illumination is seen to move off the intermediate screen. Illumination is brought back by transverse movement of the electron gun. This procedure is continued until maximum intensity and minimum spot size are obtained.

The height of the electron gun is now varied. (**Caution:** Shut off high voltage before changing height of electron gun, and discharge the gun by means of a grounding rod) until the central bright spot is about ¼ inch long as seen on the intermediate screen (see Pattern 5). If the full image, including ring of reflections of lower intensity, does not appear, the objective current may be lowered. In the above described procedure, care must be taken not to employ one of the spurious reflections as the true spot source.

If the bright filament image is not in the center of the pattern, tilting of the electron gun followed by a compensating transverse adjustment will accomplish the desired result.

4. Objective — Projector Lens Alignment (Coarse)—The action is observed on the final screen. The condenser current is focused for maximum illumination. The objective current is set to focal value with specimen in position. The projector current is set for medium magnification. Specimen holder with suitable specimen is used. The objective aperture is omitted.

A focused image of the specimen is obtained. The objective current is varied from 2 to 5 steps on the "fine" control, about the focal value. The position of the center of rotation of the image is located while the "fine" objective control is varied. The center of image rotation is moved to the center of the screen by transverse adjustment of the objective lens. The center of rotation of the image may be off the screen by several inches and as a result may not be illuminated. Use trans-

verse motion of the electron gun to keep illumination on the screen.

The center of rotation of the image may not remain at a fixed point in the image as the objective current is changed from the focal value. In this case, use the center of rotation near focus (apparent center of rotation) as the criterion for adjustment.

5. **Condenser—Objective Alignment**—The action is observed on the final screen. Condenser current is set to some high value. The objective current is varied from focal value. The projector current is set for medium magnification. Specimen holder with suitable specimen in position. The objective aperture is omitted.

Observe the final image as the objective current is reduced. That portion of the image which moves off the final screen is returned by transverse adjustment of the condenser lens. This process is continued until the lowest objective current is reached. Further adjustments are made as per steps (4) and (5) until the part near the center of rotation at focus appears at the center of the screen for the lowest and focal values of objective current, and wanders a minimum for intermediate values. Compensating transverse adjustments of the electron gun may be necessary during the above procedures. On final adjustment, the center of rotation of the image should not wander more than about 5 to 10 mm for objective current changes of ±20 ma from the focal value.

6. **Gun Alignment**—The action is observed on the intermediate screen. The condenser lens current is varied. The objective current is at focal value. The projector current is arbitrary. Specimen holder, arbitrary. Objective aperture omitted. This adjustment is a final check and similar to step (3). The image of the filament should expand into a concentric circle of illumination as the condenser current is increased from the focal value. With the condenser current high, the electron gun is tilted until maximum intensity is obtained on the intermediate screen. The condenser current is lowered and this adjustment, in combination with transverse adjustment of the electron gun, produces an intense filament image in the center of the intermediate screen.

SPECIMEN TECHNIQUE—The specimen technique is given to a discussion of the various methods employed in the insertion, examination

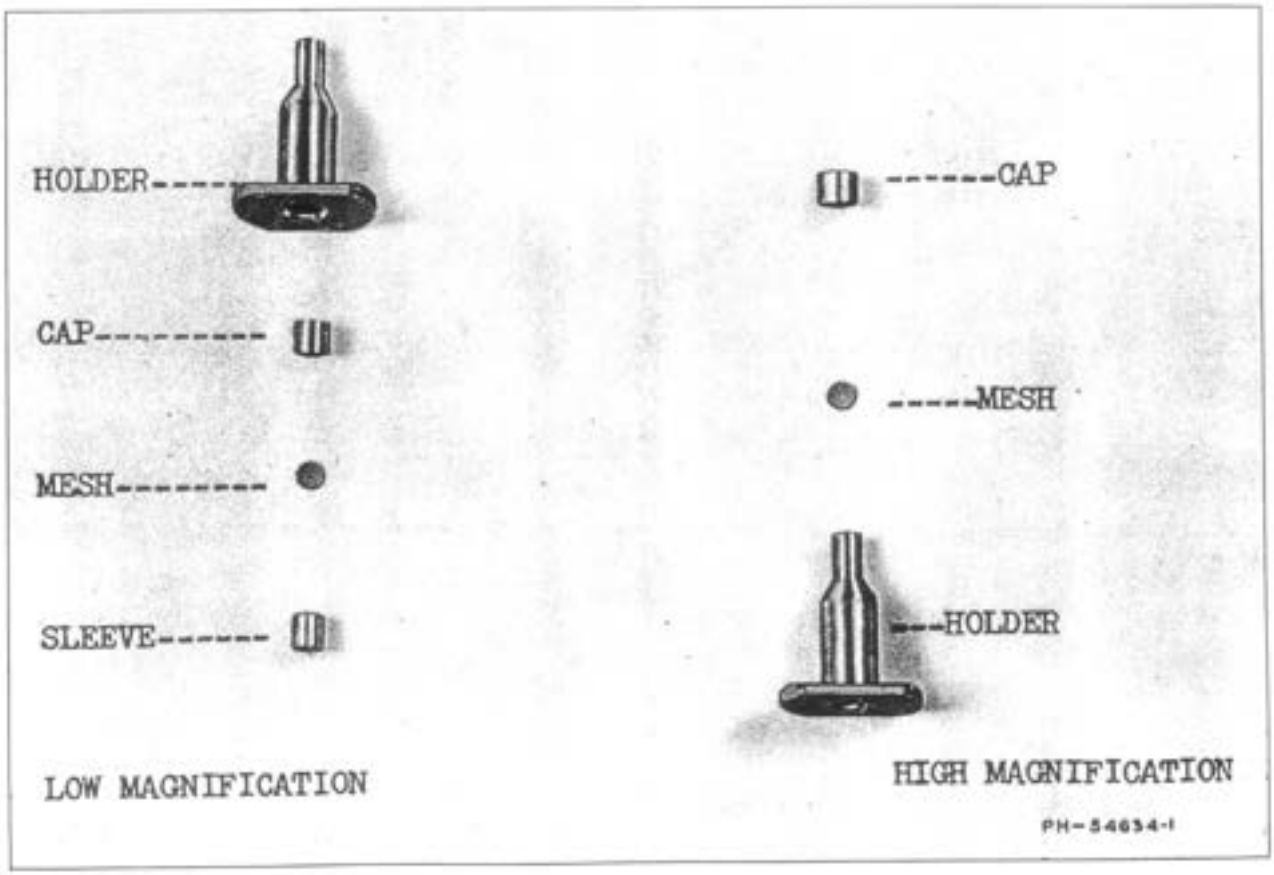

Figure 14—Specimen Holder MI-12966

and removal of a specimen. The technique is discussed in three stages, namely, insertion of the specimen; viewing and movement of the specimen; and removal of the specimen.

Insertion of Specimen—Before a specimen can be examined in the electron microscope, it must be properly prepared and then placed in one of the specimen holders or cartridges supplied with the equipment. The preparation of specimens is outlined in a later section (see page 60). The standard and a stereoscopic type of holders were described in page 16, in the section on "Viewing and Photographic Facilities." The use of the first type holder (MI-12966) is explained in the following paragraphs. The stereoscopic type holder (MI-12976) being designed essentially for photographic work, it is described separately on page 44 in connection with its special related technique.

Specimen holder MI-12966 was described as permitting two ranges of magnification. With a 60-kilovolt electron accelerating potential, the high range extends from about 3,500 to 25,000 diameters, while the low range extends from 1,000 to 4,000 diameters. In covering the high range, the specimen screen is placed in its cap and the two are then slipped on to the lower end of the specimen holder body. For the low range, the specimen screen and cap are again used but they are placed in a special recess at the top of the holder body with the screen facing downward as before. To insure proper seating and securing of the specimen screen in its new location, an additional locking sleeve is provided.

After the cap and screen have been mounted in the top of the specimen holder body, the locking sleeve is inserted in the cap opening and pressed down until it seats on the screen. The locking sleeve is provided with an extended cap which assists removal after use. With the projector lens control setting of 4 and with the specimen screen mounted in the top of the specimen holder, a magnification of about 1,000 should be obtained. Obviously, changing the specimen plane from its position at high magnification to that for low, will require a considerable change in objective (focusing) control settings. Raising the plane of the specimen in the electron axis, with the new type holder, corresponds, in terms of light optics, to a change in the ratio of object-objective to objective-screen distances.

After the specimen has been placed in the holder, the latter should be inserted by means of forceps through the door of the specimen chamber and slipped into the grooves of the cradle. After the cartridge is in place, the chamber door should be closed and clamped by turning the door clamp fully clockwise. This operation also actuates the valve system which closes the inlet valve and opens the valve in the connection to the auxiliary pump. The air-lock chamber should be left connected to the auxiliary pump for about 20 to 30 seconds. Subsequently, the door clamp should be rotated a quarter of a turn counterclockwise to

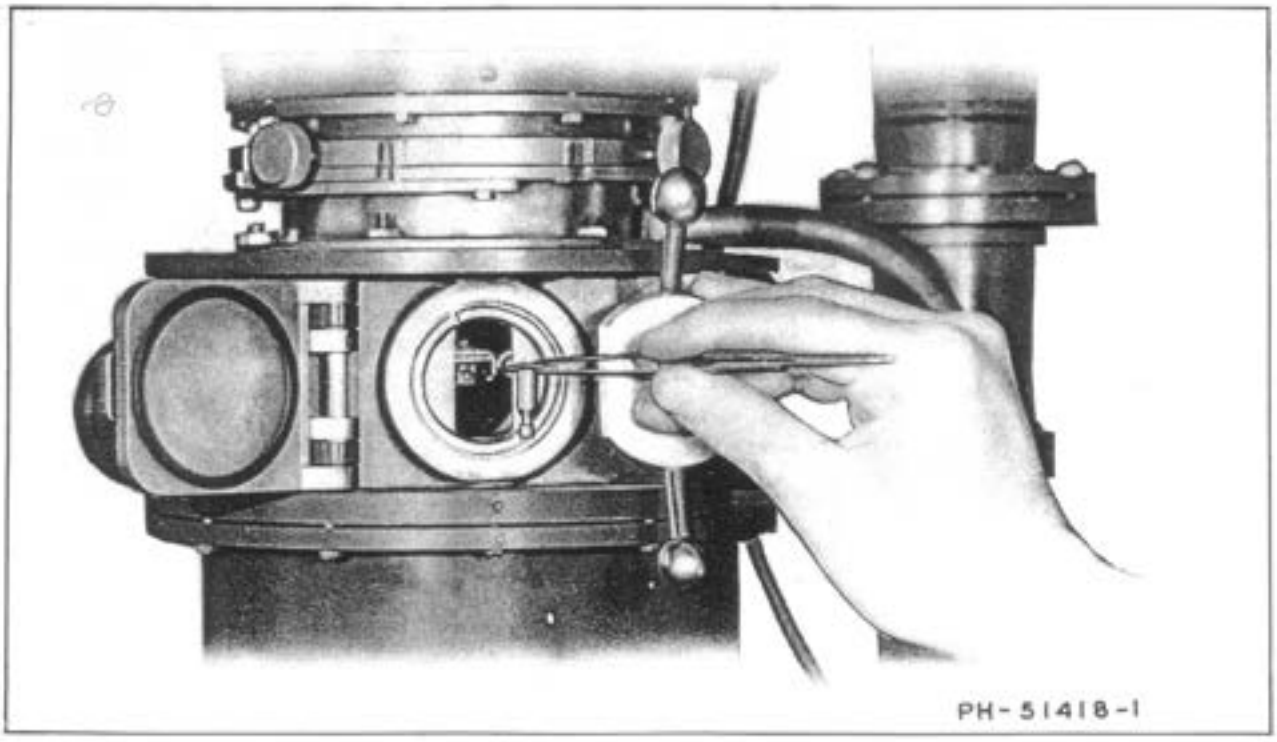

Figure 15—Insertion of Holder into Specimen Chamber

close the valve connection to the auxiliary pump, and at the same time prepare the air-lock chamber for common connection to the main column. Before proceeding further, however, the "I.G." switch, the "HIGH VOLTAGE" switch, and the "BEAM I" switch should be checked to make certain that all three are in the "OFF" position. The "THERMOCOUPLE" should be left in the "ON" position.

The specimen and air-lock control may now be turned fully counterclockwise while the operation of the specimen changing mechanism is observed through the specimen chamber port. Under normal conditions, the specimen changing mechanism should move back slowly from the auxiliary chamber, stop, and lower the specimen cradle so that the specimen cartridge drops into place in the objective pole-piece.

If the specimen changing mechanism is adjusted properly, it should seldom fail to operate satisfactorily. However, small particles of dirt or grit on the specimen cartridge may cause it to fail temporarily. Also, if the specimen moving controls are in their extreme position, difficulty may be experienced in removing or replacing a specimen, however, the mechanism should never be forced.

Viewing and Movement of the Specimen—When inserted as described above, the specimen cartridge is resting with the objective pole-piece and is, therefore, directly in the path of the electron beam. The power should now be applied and the beam, after passing through the specimen and objective, will produce an image on the intermediate screen which may be viewed through the intermediate port. Because of the relatively low degree of magnification at this point, a large portion of the specimen is brought within the field of observation and this entire field may be explored for interest value.

The two specimen remote control knobs set on the shelf of the instrument permit the alignment of that portion of the specimen which is to be used in final magnification and as a subject for photograph.

Removal of the Specimen—Before attempting to remove the specimen, the power should be turned off and positions of the specimen moving controls should be checked to make sure that they are not too far off the central position. (See page 55 for description and adjustment of these controls.) The specimen chamber air-lock control should first be turned slowly clockwise, while the action of the mechanism is observed through the chamber port. Through this port, it can be seen if the specimen cartridge is lifting clear of the objective pole-piece. Movement of the specimen cartridge must never be forced. As soon as the specimen cartridge is clear of the pole-piece, the air-lock control may be turned quickly, in the same (clockwise) direction, as far as it will go. This operation moves the specimen into an air-lock chamber to the right and isolates that chamber from the rest of the microscope body. The operator can feel the rubber gasket of the gate engage the flange, and he should take care to tighten the gate slightly beyond the first position in order to assure a good vacuum seal.

The air-lock of the specimen chamber may now be opened by turning the door clamp fully counterclockwise. This actuates the valve which allows air to enter the air-lock chamber and, at the same time, releases the specimen chamber door so that it may be opened and the specimen cartridge removed from the cradle. As in inserting the cartridge, forceps also must be used for removing the cartridge from the cradle and through the chamber door.

ELECTRON MICROGRAPH TECHNIQUE—Electron micrograph technique deals exclusively with procedures involved in photographing a specimen. The methods to be employed are discussed in the following sequence: insertion of the photographic plate; adjustment of the picture width and exposure; removal of the photographic plate; and calibration of the magnification.

Insertion of Photographic Plate—Upon inserting a loaded cassette into the carriage on the photographic chamber, the cassette release should snap into place. The door should then be closed and the door clamp turned fully clockwise. This operation opens the valve which enables the auxiliary pump to exhaust the photographic chamber. The auxiliary pump should then be permitted to evacuate the photographic chamber for about 4 to 5 minutes. Before proceeding further, however, the "I.G." switch, the "HIGH VOLTAGE" switch, and the "BEAM I" switch should be checked to make certain that all three are in the "OFF" position. The "THERMOCOUPLE" switch should be left in the "ON" position.

After 4 or 5 minutes, the door clamp should be turned one-quarter of a turn counterclockwise, which should leave it in a horizontal position. The gate on the photographic chamber should now be lowered by turning the air-lock crank fully clockwise. During this operation, the reading on the "THERMOCOUPLE" meter should be noted. On first opening the gate to the photographic chamber, the reading on the "THERMOCOUPLE" meter may drop slightly but should restore quickly. As soon as it reads "100," the instrument is ready for operation.

Adjustment of Picture Width and Exposure—To place the photographic plate in position for the first exposure, the calibrated cassette control should be turned fully clockwise. In this position, number 1 should coincide with the arrow on the cassette movement control. The control is divided into twenty parts so that moving from one number to the next advances the plate ½ inch. The arrow indicates the position of the center of

the exposure. Therefore, in order to correctly position the plate after the picture has been masked as desired, it is only necessary to calculate where the middle of the exposure should come and set this number opposite the arrow.

For example, suppose that a new plate is in and has been moved clockwise as far as possible, and it has been decided to take a two-inch picture. The center of this picture will be two half-inches from the end, so #2 is set opposite the arrow. The exposure will extend from the end of the plate (zero) to #4. If a 3-inch picture is desired next, the control should be moved to #4 to clear the first picture and then three half-inches further to #7. This picture will then extend from #4 to #10. If now a series of one-inch pictures is desired for the rest of the plate, the control will have to be moved to #10 to clear the second picture and one more division to #11 for the next exposure. The settings for the remainder of the plate would then be #13, #15, #17, #19, thus giving a plate with one two-inch picture followed by one three-inch picture, followed by five one-inch pictures. During the above described process, of course, the Masking Control should be adjusted to agree with the picture width of each exposure.

Removal of Photographic Plate—Immediately after the final exposure has been made on any plate, the filament heater and high-tension supply switches should be turned off by pushing those switches to the "OFF" position. If it is desirable to take further pictures of the specimens being observed, or to make a still more accurate check of the photographic focus, it is customary to leave the main "POWER" supply switch in the "ON" position. In this way, the coil currents are maintained at their proper values, and any hysteresis effect which may appear because of changes in the coil currents and which may give rise to changes in the focal length of the magnetic lenses is avoided.

After the final image has been made, the plate is transferred to the air-lock chamber by turning the calibrated cassette control fully counterclockwise. The air-lock chamber is then isolated from the microscope column by turning the air-lock crank handle counterclockwise until the stop is reached. In operating this handle, the rubber gasket on the photographic chamber gate, as in the case of the specimen chamber air-lock, can be felt to engage the surface of the photographic chamber opening. The air-lock crank handle should always be forced slightly beyond this point to insure a good vacuum seal between the photographic chamber and the main body of the microscope.

The door clamp at the end of the chamber should now be turned fully counterclockwise. This will allow air to enter the photographic chamber and release the pressure on the chamber door. The door to the photographic chamber may now be opened to permit the removal of the photographic plate and cassette. In order to release the the cassette from the carriage, which is permanently mounted in the photographic chamber, the cassette release should be lifted and pulled toward the operator. This releases the photographic cassette which may now be withdrawn from the photographic chamber. The cassette may now be taken to a dark room and opened for removal and development of the photographic plate

Stereo-micrographs—Stereo-micrographs may be obtained through use of a special specimen holder (MI-12976). When employed as described below, this holder will produce micrographs having a magnification of about one-half that obtained with specimen holder MI-12966 when the specimen is in the "high" magnification position. The angle Θ in the following description is approximately 8°

In optical light microscopy, information regarding the three-dimensional structure of materials may be obtained by one of at least three methods. These include the methods of series sections, optical sectioning, and stereo-photomicrography. Owing to the nature of electron microscope specimens, and the enormous depth of focus obtained in electron microscope images, the first two of these methods are not available to the electron microscopist. On the other hand, the electron microscope can be readily adapted to produce stereo-pictures and give accurate information regarding the third dimension in the specimens. The actual experimental procedure is essentially the same as that used in obtaining stero-pictures with the light microscope, which consists in obtaining micrographs of the same field from slightly different points of view. In the electron microscope, this is accomplished by the use of a specially constructed specimen cartridge which is provided with a means of adjusting the angle between the axis of the microscope and the normal to the plane of the specimen. Two micrographs of the desired field are made for which the above mentioned angle has equal but opposite values.

The specimen holder is made in two parts: an outer part which has the same outside dimensions as the standard specimen holder, and can replace the latter in the specimen chamber; and an inner part which is a cylindrical tube with the specimen clamped at its lower end. The geometrical arrangement is as follows (see Figure 16): the central axis $OX'O'$ of the outer part coincides with the incident electron beam when in operating position, while the central axis of the inner part XX' makes a small angle $\Theta/2$ with it. The parts are accurately made so that the central axes of the two parts intersect, and the specimen is placed in the plane perpendicular to the axis of the inner part at the point of intersection of the two axes, X'.

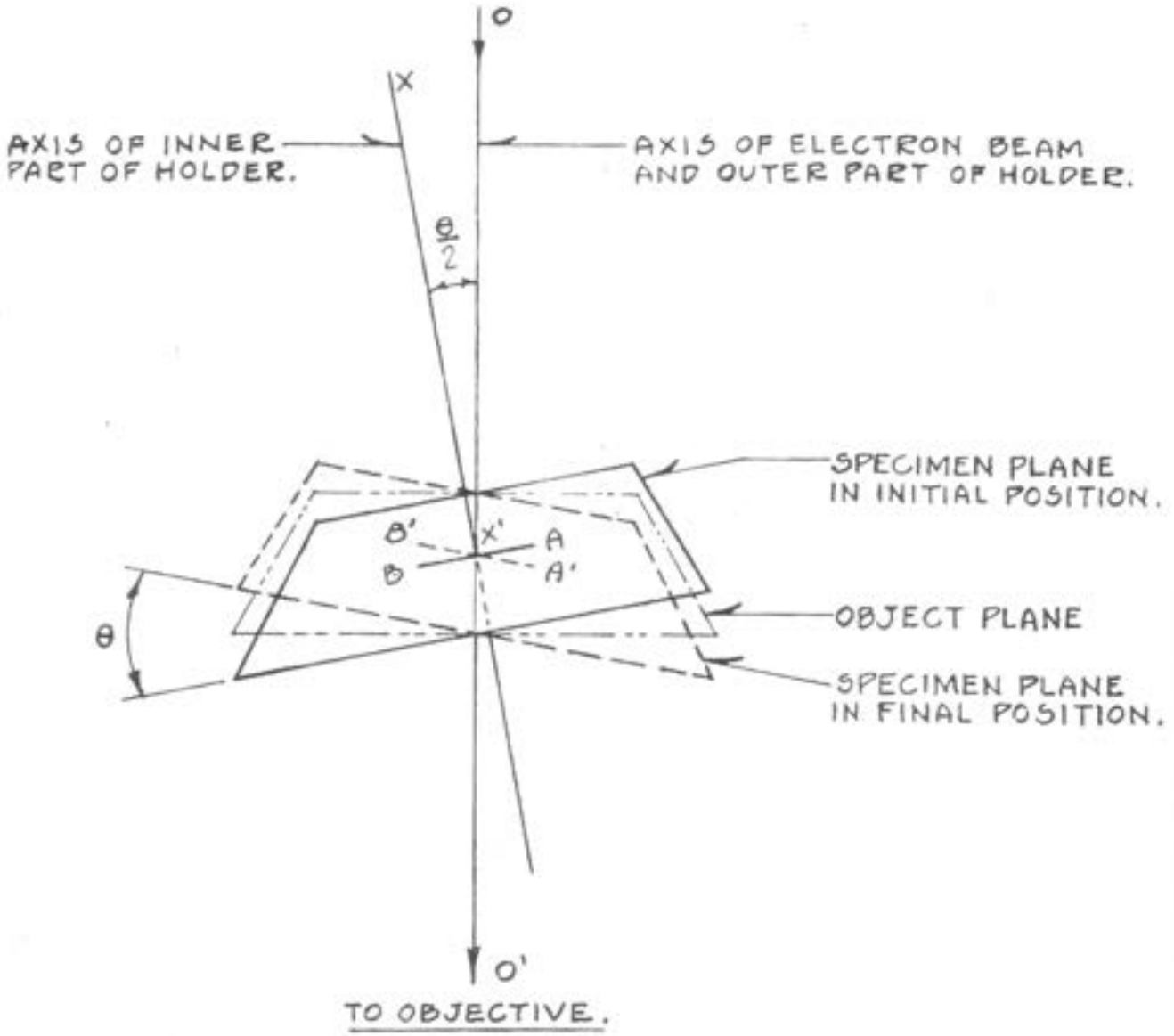

Figure 16—Stereo-Micrograph Procedure (MX-246356—Sub. 0)

The procedure for obtaining a stereo-micrograph is as follows: the specimen is inserted and a suitable field of view selected, for example, Point A. The microscope is focused and the photographic record made in the usual way. To make the second image of the stereoscopic pair, the whole specimen holder is removed through the air-lock, the inner part of the holder is rotated through 180 degrees, the complete holder is rotated about the axis of the outer part through 180 degrees and reinserted in the microscope. The same field of view is found and a second micrograph made. Geometrically, these operations consist of: (1) a 180-degree rotation of the specimen in its own plane about the axis XX^1. This places the point A below the object plane of the objective so that the angle AX^1O (which was $\pi/2 - \theta/2$) now becomes angle BX^1O (equal to $\pi/2 + \theta/2$); (2) a 180-degree rotation of the specimen about the axis OO^1. This causes the specimen point, which was at B as a result of the first operation, to move to A^1. The angle BX^1O becomes A^1X^1O but remains unchanged in value. Since the projection of the specimen point A on the object plane of the objective coincides with that of A^1, the same field of view should be observed when the specimen holder is reinserted in the microscope. In actual practice this is not absolutely true due to slight errors in construction, but the field of view observed in the first position is usually so near to the observed field in the second that it can be found without difficulty. The only differences in the two micrographs are the slight difference in magnification caused by the slight change in the distance between the specimen point and the objective, and those differences due to the fact that the plane has been tilted through an angle of θ. The former effect is either negligible, or else can be corrected in the preparation of the print, by a slight enlargement of one print. The latter effect accounts for the stereoscopic or three-dimensional appearance of the specimen when the finished prints are properly viewed.

In order to obtain the proper results, it is essential that the prints used for stereoscopic viewing be suitably prepared and oriented. Proper orientation of the prints is particularly important due to the fact that magnetic lenses cause an arbitrary amount of rotation of the image. It is therefore necessary to rotate the prints about corresponding points **until all the displacements in the image that are due to the tilting of the specimen are parallel to the line joining the eyes of the observer.** A simple way to accomplish this result is to take the stereoscopic pair of prints and superimpose them in front of a bright light so that both images can be seen. Some point in the field is selected as the point that should appear nearest the observer, and the two images of that point are made to coincide. It will then be seen that the images of other corresponding points of the field of view do not exactly coincide, but are displaced slightly relative to one another in arbitrary directions. If the proper foreground point has been selected and the displacements are due to the stereoscopic effect only, the other parts can be made all parallel by rotating one picture over the other until the required condition obtains. The angular position of each print should then be accurately noted and maintained when the prints are permanently mounted for stereoscopic viewing.

A few remarks should be made in regard to the obtaining of successful stereo-micrographs. Specimens which show sign of moving or changing of their own accord while in the electron beam or otherwise, do not in general give true or even good stereo-micrographs. By shortening the time of observation of the specimen between exposures, changes in dimension of parts of the specimen, caused by metal sputtered from the wire screen support, will be reduced to a minimum. This is particularly true of specimens mounted without supporting membrane.

The rules for ordinary stereoscopic photography should be followed in making up prints, attention being paid to those details which can produce confusing effects, such as the position and shape of the borders.

It should also be pointed out that stereo-micrographs obtained in this way produce a dissociation of perspective and three-dimensional parallax phenomena. This is due to the fact that the perspective in the images corresponds to that which would be seen in an object situated in the neighborhood of 100 meters from the eye while the three-dimensional parallax effect corresponds (for $\Theta = 8°$) to that which would be seen in an object at a distance of about 50 centimeters.

Calibration of the Magnification—Prior to shipment, the electron microscope is tested for magnification at one specified electron voltage and objective coil current. However, operation of the microscope at different electron voltages or with different specimens will change the magnification calibration. Therefore, if it is necessary to know the magnification with considerable accuracy, it is advisable for the operator to recalibrate the instrument to satisfy his own particular requirements. Two calibration methods are described below.

a. **First Calibration Method**—Generally speaking, calibration of the magnification is measured by comparison of photo-micrographs of a test specimen taken with the Electron Microscope and with a high-powered calibrated light microscope. For this procedure, the specimen is mounted in a Specimen Holder MI-12966 such as described before. A fairly large specimen is chosen; i.e., one which appears in about 3 or 4 openings of the specimen screen (about 150μ x 150μ), and which shows a number of readily distinguishable irregularities on its boundaries. A portion of this specimen is photographed in the "high magnification" plane of the specimen holder at various settings of the projector control; the specimen is then removed to the "low magnification" plane of the specimen holder and the photographing process repeated. A micrograph is now taken of the whole specimen in a calibrated light microscope and the magnification is computed for both "high" and "low" magnification planes of the specimen. The light micrograph is used to calibrate the intermediate or "low" magnification series and the intermediate series is used to calibrate the high magnification steps. Obviously, the use of a larger specimen for the calibrated light micrographs should reduce the error of observed measurements by a large percentage.

b. **Alternate Calibration Method**—An alternate method of calibration of the magnification involves the same photograpic procedure as described above, but instead of measuring the specimen with a light microscope, a collodion replica is made of a diffraction grating having about 30,000 lines/inch. This replica of known line spacing can be photographed with the electron microscope at a projector setting which permits about a dozen lines to be included in the field and serves as a direct calibration of this projector setting. The replica may be saved and used to recalibrate the microscope at any time.

One precaution must be observed in using this method. The grating replica undergoes some distortion in stripping, and the line spacing should be determined by measuring the **replica** with a light microscope using a high power dry objective. Since magnification depends on the current in the objective and projector coils as well as on the electron accelerating voltage, meter readings and control knob settings must be recorded with care for all calibration points. In addition, these readings must be watched for repetitive constancy, once calibration has been made. Presuming that the Microscope has been calibrated at fixed values of objective current and accelerating voltage; in a given specimen plane; at various

values of projector current control steps, there are certain factors which will affect repetitive accuracy. These are listed below:

1. Line voltage changes—(corrected by line regulating transformer).

2. Inconstancy of specimen plane, caused by variations of specimen height in supporting media; variations in supporting media; mechanical inaccuracies of exact replacement of specimen in calibrated plane. (These variations—focusing corrections by change in objective current may be compensated by means of the objective "Vernier" control, as explained further below.)

3. Lens hysteresis effects (corrections for these effects explained below).

4. Aberrations—dimensional changes as a result of distortion, can be reduced to a minimum order, if measurements are confined to the central area of the electron cone.

5. Lens current or accelerating voltage changes (overcome by correcting electronic circuits—tubes, dry battery standards, or component parts).

6. Foreign particles in lens pole pieces (corrected by keeping inner configurations of pole pieces, surfaces of apertures and all points near to the electron beam free of dirt or particles subject to electrostatic charge).

For a magnification calibration at a fixed objective current (given settings of the "coarse" and "fine" objective knobs) and at selected accelerating voltage, changes outline in item 2, above, i.e., changes in objective vernier settings, are taken into account as follows: the objective vernier control does not affect meter readings; a mark is made on control panel showing calibration point for objective vernier control; approximate correction can be made by using the following formula:

$$\frac{n}{270} \times 4\% = X_c$$

where n = degrees departure of vernier pointer from calibrated position.

270 = total degrees rotation of objective vernier control.

X_c = per cent change in magnification (for any given projector knob setting). The sign of X_c is negative if the correction is made in counterclockwise direction and positive if it is made in clockwise direction.

Hysteresis effects listed in item 3 above are compensated for as follows: The projector and objective current controls should be operated in one direction only (preferably clockwise) when calibrating or making succeeding measurements. Otherwise, hysteresis effects in the iron cores of the deflecting coils will affect the calibration accuracy. If a large change (greater than 10 ma in the projector or greater than 6 ma in the objective) in current **direction** is required, it is best practice to reduce the affected circuit current to a minimum and advance slowly to the desired value.

It is safe to assume that, if necessary precautions are taken and careful measurements made, the error of magnification computations will not exceed 10 per cent.

NORMAL METER READINGS

"THERMOCOUPLE"—

Right-hand Meter	100
Left-hand Meter	calibrated

Ionization Gauge ("I.G.")—

Right-hand Meter	0.5 or less on "10" scale
Left-hand Meter	2.5 ma

"BEAM I" Meter ..... 450 ma (approx.)

"TEST" Meter

Switch Positions	Current Readings
1. Rectifier	70 ma
2. Filament	40 ma at max.
3. Exciter	25 ma
4. PA	150 to 300 ma
5. Filament Regulator	150 ma
6. Condenser	adjustable
7. Projector	adjustable
8. Objective	adjustable
	Voltage Readings
9. +Regulator	400 v
10. PA	500-650 v
11. –Regulator	350 v

MAINTENANCE

Familiarity with the methods employed in routine care and servicing is essential in maintaining the proper functioning of the microscope. Therefore, the following discussion on "MAINTENANCE" should be carefully read and consulted as an adjunct in the periodic check-ups of the instrument. To obtain the ultimate in micrograph results, it is essential that every electrical and mechanical component of the Electron Microscope —from electron gun to photographic plate—be in good condition and in proper alignment.

WARNING—Voltages used in many of the circuits of the electron microscope are dangerous to life. Circuit checking and trouble shooting should be accomplished by no less than two operators. Even though power has been turned

off, certain capacitors in the circuits are capable of storing electrical energy for considerable periods of time at voltages which are dangerous to life. Before touching any of these circuits, they should be grounded and discharged with a "grounding rod". The grounding rod must have a well-insulated handle. It must be grounded through a circuit which must be continuous and of low resistance. The grounding connector must be flexible to withstand usage. It should be exposed so that its continuity may be checked readily. In addition to grounding, it is accepted and good practice to test every circuit requiring examination with a voltmeter, before physical contact is made.

NOTE—As a general rule do not remove tubes from circuits which are in operation.

ROUTINE CARE—Before operating the microscope, a preliminary check of the instrument should be made. In the course of routine inspection, the following items should be checked as described:

a. The microscope column, chassis and rotary pumps should be dusted. The entire instrument should be kept dust-free.

b. All tubes should be tested on a reliable tester and replaced when the mutual conductance falls below 70 per cent of its initial value.

Regarding the tube data, voltage tests and checks should be made with a voltmeter having a resistance of no less than 20,000 ohms/volt. All tubes should be checked periodically. For those tubes which can be tested on regular tube checkers, it should be pointed out that most tube testers, check emission only. This type of test is satisfactory for most purposes but is not sufficient for microscope work. Tube tests should reveal operating characteristics such as mutual conductance or amplification factors, etc.

c. All "B" batteries (45 v) should be tested and replaced when their values fall below 37 volts.

Caution: The voltage of the battery B3 (shown in "Block P" on the schematic diagram) is generally tested at the various taps of the "HIGH VOLTAGE" switch S14. The total nominal voltage of this battery is 550 volts. The voltage at the first tap (bottom fuse) is approximately 250 volts. The operator should be aware of these voltage values existing at these points.

d. The test meter should be checked by adjusting the range switch to its various positions and comparing the results obtained with the normal meter readings as tabulated at the end of the section on "OPERATION" (see page 47).

e. All controls on control panel should be cleaned periodically, using solvent and fine sandpaper.

f. The fan on the door of the microscope cabinet should be lubricated periodically. Care should also be taken that the blades are not damaged or thrown off balance.

g. The corona shields should be kept highly polished at all times.

h. The rotary pumps should be examined before operation. (See "Care of Rotary Pumps".)

NOTE—High voltage apparatus in the electron microscope is contained within a tank filled with transformer oil. Checks should be made periodically to be certain that the tank is properly filled (to within $\frac{3}{8}$" of the bottom surface of the cover when cold). The oil employed is inflammable and care should be exercised in handling to avoid spilling. In addition, checks should be made by the purchaser before installation and precautions taken to comply with local fire or electrical regulations.

SERVICING—The following section on "Servicing" is given to a discussion on (a) care of rotary pumps, (b) replacement of filament, (c) replacement of objective aperture, (d) preparation of the objective aperture, (e) realignment of the microscope, (f) care of the diffusion pump and (g) checking of the vacuum leaks. A knowledge of the procedures involved to rectify any mal-functions that may arise will greatly expedite the technician, in that the loss of time in use of the instrument will be minimized.

Care of Rotary Pumps—During shipment, the intake nipple of the rotary pump is closed to prevent entrance of foreign matter into the pump. During actual use of the pump, every precaution should be exercised, to prevent impurities from entering the pump.

Before operating remove the top plate of the pump and fill with oil to the indicated level. An oil level line is indicated by an arrow inside the case of the rotary pump. The oil should stand at this level when the pump is in operation. If insufficient oil is used, a good seal around the vane may not be maintained. If too much oil is used, the oil may back through the pump trap into the vacuum line. After operation, the oil may back into the pistons and upon removal of the top plate the oil supply will appear to be insufficient by falling below the oil line level. Caution should be exercised in that no oil be added before the pump wheel has been given a number of turns by hand. This operation will release the oil in the pistons, thereby bringing the oil up to normal operating level. The proper direction for the rotation of the wheel is indicated on the pump near the pulley.

The oil supplied with the pump is especially prepared for high vacuum work. For maximum pumping speeds at low pressures no other oil should be used. After changing oil, the pump

must be run for some time on a closed system before lowest pressure is obtained.

The vanes are individually fitted. They should not be removed unless it is absolutely necessary, and then must be replaced in their original position.

Due to the operation of the ball valve in the exhaust stage, the rotary pumps normally operate with a clicking sound which becomes sharper as the pumps warm up. On continuous duty the oil temperature reaches 50 or 60 degrees Centigrade.

If the pumps in operation are subjected to vapors, these should be trapped to prevent contamination of the oil. If the vapors are corrosive, they may attack metal parts of the pump. If the vapors are non-corrosive, they may be pumped through the mechanism, in which case the oil should be changed more frequently. Drain plugs are provided at the base of the pumps for removal of oil in the case.

The rotary pumps have wool-packed bearings which should be lubricated every three months.

The belt adjustment in mounted pumps is made by loosening the motor bolts and sliding the motor slightly forward or backward.

Replacement of Filament—In order to obtain sufficient emission for an adequate bright final image, it is necessary to run the electron microscope filament at a temperature which is considerably higher than that used in ordinary electronic tubes. As a result of this higher operating temperature and because of the relatively poor vacuum used in the microscope, the filaments deteriorate rather rapidly. In operation, this deterioration becomes apparent by a change in the operating position of the filament control. As the filament becomes thinner, less heating current is required to heat it to the temperature at which the total beam current is 450 microamperes. As the filament is used, the position of the knob marked "FILAMENT" at which a total beam current as read on the "BEAM I" meter registers 450 microamperes will gradually recede to the left. Finally, it will be found that with the "FILAMENT" knob turned as far counterclockwise as it will go, the beam current on the "BEAM I" meter will be about 500 microamperes and eventually will be sufficient to overload the high tension system and actuate the protective relay and "OVERLOAD" lamp. When this point is reached, it is necessary to replace the filament. The operations required to accomplish this are set forth below.

The first step is to throw all of the switches of the equipment to the "OFF" position, in particular those of the ionization gauge filament circuit, and those controlling the power, high voltage and filament heater. Next, close the main valve.

Then, in order to gain access to the filament head, remove the cover of the top microscope canopy.

To remove the electron gun assembly, it is first necessary to disconnect the two filament leads coming from the upper corona support ring. The filament connection to the top center of the electron gun is made fast between two hex nuts on the threaded portion of the cathode rod. When tightening or loosening this connection, care should be exercised to prevent excessive torque being transmitted to the cathode rod so that the wax seal will not be damaged. The upper corona ring should be wiped free of dirt so that its effectiveness will not be impaired. This rule also applies to the loose corona ring at the bottom of the electron gun assembly.

After the electron gun clamp ring and gasket have been removed, and before proceeding further, it is necessary to break the vacuum in the whole system, and allow the Microscope column to rise to atmospheric pressure. This may be done by opening the specimen chamber door with the specimen chamber main valve in the open position.

The electron gun assembly may now be removed from the glass cylinder support. Removal of the outer shield permits access to the filament assembly. In removing the filament assembly from the supporting plate, it may be necessary to push aside the high-voltage corona supply ring. It should be noted here, that in removing the cathode assembly, it is necessary to be careful so as not to scratch or nick the polished surface of the outer shield. The outer shield may now be removed by taking out the shield screws and sliding the shield off the inside assembly. The filament holder assembly is then removed from its socket and replaced.

The outer shield should be cleaned and on reassembly into the column, it should be free of finger stains, etc. Cleaning can be accomplished easily with a small piece of chamois. The filament assembly is removed by loosening the two small set screws found on either side of the filament assembly support-block. Burned out or defective filament assemblies should be salvaged as far as possible since the supply of suitable mica at this time is quite limited.

The filament assembly support may be disassembled by unthreading it from the remainder of the whole. The top of the center circuit connector of the filament assembly support is silver plated. This surface should be checked and cleaned as well as the mating connection, the silvered lower end of the cathode rod. On reassembling the filament support to the rest of the gun assembly, sufficient pressure should exist so that the two silvered surfaces are in good contact. Over-tightening the assembly is apt to crush the lava washer surrounding the connector stud and insufficient pressure will produce poor circuit conditions.

Before installing a new filament assembly, make sure that all its connections are tight. Normal

dimensions for the filament were given on page 14. The cold resistance of the filament assembly measured across the connector studs should be approximately 0.15 ohms. The mica should be free of dirt or foreign material. The filament assembly is installed in the filament support so that the plane of the mica is parallel to the filament support face. The support-screws are tightened to insure contact and rigidity.

The tantalum aperture in the end of the outer shield should be clean and free of burrs. The aperture may be cleaned by boiling in caustic soda and rinsing in distilled water. An eyepiece of at least 5x power should be used to examine the aperture for cleanliness.

At final assembly of the outer shield to the electron gun, the apex of the filament is checked for concentricity in the aperture. The apex should remain concentric to the eye as the assembly is rotated. The tungsten filament may be coaxed and bent to obtain this condition by means of a small pair of smooth jaw pliers. A used filament is brittle and will not withstand such treatment.

Having checked or suitably adjusted the position of the filament, the entire cathode assembly may now be replaced in the top of the electron gun and the gasket replaced with the clamping ring and the clamping plate screws. Before replacing the gasket, however, the surface of the supporting plate and the flange of the sylphon support should be examined for particles of grit or dirt. The clamping plate screws should be replaced and screwed up as tightly as possible. In doing this, the tightening process should be done in rotation around the gasket. Once again, care should be exercised in order to avoid twisting the sylphon adjustment.

After tightening the clamping screws the corona shield may be replaced to rest on the supporting plate, and filament connections made to the filament holder assembly and insulating washer. The cabinet cover may now be replaced.

To save time on repumping the body of the microscope, the door clamps of the photographic chamber and object chamber may be turned to the position for connecting the auxiliary pump to the air-lock chambers. If the internal gates have been left open, the whole system will be evacuated by the auxiliary pump.

When the whole chamber has reached a rough vacuum, the main valve may be opened and the door clamps turned to the neutral position. This connects the main body of the microscope through the diffusion pump to the main mechanical pump. A good vacuum should be attained very quickly. It is important to keep the main rotary pump and oil diffusion pump in operation during the entire procedure of changing the filament if the time required for the operation is to be kept at a minimum.

After long operation, the inside of the glass cylinder surrounding the electron gun may have a brownish coating. This coating is probably a combination of carbon and various oxides, principally tungsten. While the coating does not seem to have any appreciable effect on Microscope operation, it can be removed by boiling the cylinder in caustic soda. The outside surface of the cylinder must be kept clean to avoid corona discharge, particularly under conditions of high humidity. Under extreme conditions of humidity, it may be necessary to apply a thin film of light oil to the outer surface of the cylinder to reduce corona effects.

Damage to the wax seal at the top of the cathode rod can be repaired easily through the application of a hot soldering iron and, if required, a small amount of wax. A good wax seal is distinguishable by a shiny surface free of cracks and bubbles.

Lens Coils—The respective functions of the condenser, objective and projector lens coils were described in a preceding section.

The magnification for given conditions of the objective and projector systems is roughtly proportional to the square of the current in the lens coils. Thus, the higher the current required for focusing an image, the greater will be the magnification of the objective. Likewise, more current in the projector means higher magnification.

The electronic circuits of the microscope are arranged to carefully regulate the current in the lens coils and the regulation obtains for each chosen value of current. Since the lens coils constitute the circuit loads for their respective regulators, the circuits will be considerably overloaded if the coil connector plugs are disconnected when the circuits are operating. Likewise, the lens coils may be ruptured from the inductive back kick. If there is no current flow indication at the test meter for any lens circuit, the defective circuit should be turned off immediately. The regulating circuit, the connecting cable and the plug and the lens coil itself should be checked to ascertain the cause of the difficulty. Characteristics of the lens coils are as follows:

	Condenser	Objective	Projector
Resistance	420 ohms	700 ohms	700 ohms
I min.	20 m. a.	20 m. a.	20 m. a.
I max.	120 m. a.	140 m. a.	120 m. a.

In manufacture, all lens coils are tested for quality of insulation by application of 1000 volts to ground.

Pole Pieces—Each lens contains a pole piece, specifically designed for its particular function. Proper operation of these cannot be obtained unless absolute cleanliness exists throughout their inner configurations. Concerning the matter of cleanliness, the following components come in

contact with the electron beam and therefore are subject to the rigid requirements of cleaning and service.

1. Electron gun shield and aperture.
2. Anode.
3. Filament focusing screen and condenser aperture.
4. Specimen holder.
5. Objective pole piece and aperture assembly.
6. Projector pole piece and intermediate screen.

The objective and projector lenses have removable pole pieces. (See page 52 for detailed procedure for removing and replacing the objective pole piece.) The condenser pole piece is a fixed part of the lens and cannot be removed for cleaning. The pole piece aperture of the condenser is relatively large and therefore does not require other than casual inspection for dirt or other foreign materials.

The objective and projector pole pieces require routine inspection and must be carefully cleaned to remove all traces of foreign material. Preliminary cleaning can be accomplished with a rinse in acetone or carbon tetrachloride and should be followed by hand drying with a lintless cloth. A toothpick or, better still, a piece of orange wood can be used as a reamer to ream clean the sides of the hole. After this cleaning, the pole piece hole should be examined carefully with at least a 5x eyepiece. Particles still adhering can be removed with fine tweezers or the orange stick. Compressed air cleaning is not recommended because of the dirt particles inherent in the blast. After cleaning, the pole pieces should be protected from dust if they are not to be used in the microscope column immediately.

The prime cause of image movement in micrographs is dirt in the confines of the pole pieces, apertures, specimen holder, etc. Too much care is never given in insuring cleanliness in these accessories. Fixed images also depend on column alignment. A properly aligned column produces image rotation only if accelerating or lens voltages are varied. Changing the beam current in an aligned column having constant accelerating and lens voltage is equivalent to changing the quantity of illumination and should not produce image movement unless there is dirt in the system.

Any foreign material in the confines of the optical system will assume electrostatic charges from the electron beam. If the foreign material is in the form of an insulating or semi-insulating particle or film, the charge accumulation will raise the potential of its surface. The field produced between this charged surface and the microscope column will deflect and distort the electron beam. If the foreign material is a good insulator its surface may charge to such a potential that the insulation breaks down suddenly and the charge disappears. At the same time, the potential between the surface of the material and the microscope column also disappears. Immediately, the surface of the foreign material will begin to charge again. This results in a periodic deflection of the image, characterized by a slow drift in one direction followed by a quick restoration to the original position. If the conductance of the foreign material is sufficient to prevent the surface reaching the breakdown potential, a steady state may be reached, for which the surface of the particle reaches a steady potential and the image is permanently deflected and distorted by a constant amount. Under these conditions, however, the potential of the surface and hence, the amount of deflection of the beam depend on the number of electrons striking the particle, i. e., on the intensity of the beam. Thus, if the beam intensity changes for any reason, the image will move accordingly and result in unusable micrographs. Likewise, the lens aberrations caused by these spurious fields are sufficient to render micrographs inferior even though the spurious field potentials tend to remain fixed and constant.

The above described image movements and their causes are not to be confused with random image movement caused by possible changes in the electrostatic charges accumulated in the specimen itself. These effects depend on the type of material and its disposition and dispersion on the supporting film and screen. However, image movement of this type is quite often continuous in a given direction. Charges then accumulate on the particles of the specimen and as a result of their mutual repulsion cause film rupture and movement. Mutual attraction takes place between charged particles and the screen where these are close together, and also causes rupture and movement. In rare cases, materials such as animal fur and various types of cellulose have exhibited oscillatory motion. The cure for these cases and others involving the specimen itself must be found by experiment, and at this writing, there are many materials still lacking satisfactory "quieting" techniques.

While line voltage regulation minimizes image movement by reducing beam current changes, the remedy in this case overcomes effects rather than causes. On the other hand, line voltage regulation is of value in maintaining the microscope load potential within the allowable limits of 115 to 125 volts R. M. S.

Projector Pole Piece—The projector pole piece is made of brass and soft magnetic iron, and should be handled with care. In order to prevent scoring and binding of the threads when screwed tightly, a small amount of octoil may be applied on the threads and bearing surfaces. Cleaning should be done very carefully in order to maintain the journal finish and eliminate possibility of scratching. Such cleaning is best achieved by means of an ordinary hardwood round toothpick or orange wood stick and a good quality chamois.

The projector pole piece assembly is furnished with two apertures and two spacers. The long spacer and larger aperture should be used together for the low magnification range. This range may extend up to approximately 17,000 for the highest projector setting.

With the short spacer and small aperture, the magnification extends from 6000 or 7000 to 25,000 approximately. This range may be further increased by increasing the projector battery voltage from 30 volts to 40 or 45 volts. However, the upper magnification operation should be checked carefully, since the projector coil regulation becomes limited in the neighborhood of 200 milliamperes. This particular lens setting is most useful for magnifications greater than 10,000 diameters, whereas the long spacer and large aperture are best suited for the normal operating range.

When installing the projector pole piece, it should be made certain that the pole piece seats accurately in the coil enclosure. The faces and seat should be cleaned thoroughly. Rust and corrosion must be removed with crocus cloth, and the bottom face of the pole piece should be tested with mechanic's blue to make certain it seats properly. Incorrect seating may result in an image which first increases in size and then becomes distorted and smaller as the projector lens current is increased.

Cleaning of Apertures—The apertures used in the microscope column have the following characteristics:

	Electron Gun	Condenser	Objective
Material	Tantalum	Copper	Copper
Dia. (inch)	0.100	0.020	0.001 approx.

A recommended method of cleaning the condenser aperture is as follows: the aperture is given a preliminary cleaning with solvent, orange stick and chamois; the aperture is then held in a benzine flame so that foreign particles are burned out and so that a thin carbon film is deposited; the aperture is held far enough away from the flame so that an oil film is not picked up. The thin coat of carbon is left on the aperture disc. This coating is conducting and therefore any foreign material covered by it, is rendered ineffective from an electrostatic standpoint. The carbon coat likewise tends to reduce secondary emission and therefore, the effect of spurious illuminating sources.

The above described technique can be adapted equally well to the electron gun.

If an objective aperture is not used, the brass support tube should be discarded also. Without an aperture, the support tube may produce beam reflections and unsatisfactory micrographs. If an objective aperture is used, it should be as close to 0.001" dia. as possible. An objective aperture will enhance resolution and contrast for a misaligned electron gun system. On the other hand, a critically adjusted electron gun dispenses with the need for an objective aperture. The methods of preparing, adjusting, and installing objective apertures are fully described in the following sections.

Other components of the electron beam system not covered in the above instructions can be cleaned by employing solvent, chamois, orange stick and distilled water as best suits each condition. Parts which are coated with Willemite should be carefully handled to avoid damage. The edges of the apertures of the condenser and intermediate screens should be freed of Willemite inasmuch as this material is highly electrostatic. The pointed end of a toothpick will remove Willemite at the surface edge while the body and end of the toothpick can be used in the aperture.

Replacement of Objective Aperture—After the microscope, equipped with a new aperture, has been in use for from one to two months, a few effects will become apparent which indicate that the limiting aperture in the objective lens is becoming coated with semi-insulating material.

Indications of the presence of this material are, first, a change of focus on the objective with a change in the illuminating intensity. Second, a lateral shift of the image in good focus with change in illuminating intensity.

These effects are usually accompanied by a loss in resolution in the images obtained under these conditions. When the definition obtainable with the electron microscope decreases to the point where satisfactory pictures of the material being investigated can no longer be obtained, it is necessary to replace the limiting aperture in the objective lens. The procedure to be followed in this case is described below.

It is first necessary to let air into the whole microscope system with the exception of the diffusion pump, which may be left running with the main valve closed if it is desirable to make the change quickly.

Air should be admitted slowly to the column by turning the specimen chamber cam valve to the open position with the specimen and air-lock control valve wide open. (**NOTE:** This procedure should be used whenever it is necessary to fill the microscope with air. If, for any reason, air must be admitted through the photographic chamber, the bottom fluorescent screen should first be raised, as otherwise the in-rushing air will make it fly up and possibly cause damage.) The spanner nut behind the air-lock door should then be removed and the cradle mechanism pulled out. A long screwdriver may be used to support the cradle during this procedure so that it does not drop and catch on the wall of the specimen chamber. Then the clamp ring holding the main chamber valve (specimen and air-lock control

valve) is removed, and the valve assembly is pulled out carefully so that the sylphon does not scrape the wall of the specimen chamber. By inserting the pole piece forceps or a screwdriver through this hole, the spring clips holding the stage insert are pushed aside and the insert is lifted out with the forceps. The pole piece can then be lifted out.

To reinsert the pole piece, the same procedure is followed in reverse order. Care must be taken to prevent dust from collecting on any of the parts when they are put in the microscope.

When the cradle is replaced, it must be positioned so that the specimen holder will drop smoothly into the hole in the stage as the valve is opened (see page 42). The adjustment is made as follows:

When the valve is replaced, the clamp ring should be left loose enough to permit rotation of the valve assembly. Then the cradle mechanism should be reinserted so that the two pins behind the spanner nut slip in easily. A specimen holder should then be placed in the cradle and the main valve (specimen and air-lock control valve) operated. If the holder does not drop into the hole in the stage, the valve may be rotated to the left or right slightly until the operation is satisfactory. The clamp ring and spanner nut should then be tightened further and the positioning rechecked. When the specimen holder moves in and out of the stage smoothly with the clamp ring vacuum tight, the microscope is ready for operation.

If it should be found impossible to correctly position the specimen holder by rotating the specimen chamber valve, the point at which the holder begins to drop into place can be adjusted by turning the screw located just below the two pins which fit into the back of the cradle mechanism. After making such an adjustment, it is essential that the nut on this screw be tightened firmly.

The limiting aperture consists of a one-mil or 25-micron circular hole in a conducting metal sheet. Its purpose is to limit the imaging rays to only those which leave the specimen in a direction almost parallel to the axis of the lens. However, if the surface of this diaphragm becomes coated with a layer of semi-insulating material, it will, under action of the electron bombardment, carry a surface charge which, in turn, produces a difference of potential between the surface of this layer and the conducting material of the diaphragm.

Effects similar to those described above in the section entitled "Pole Pieces" will then occur, disturbing the image in a variety of possible ways. (See page 51.)

The conditions described above will occur after a considerable time of normal operation of the microscope. This is due to the formation of a somewhat carbonaceous deposit at the point of impact between the electron beam and the limiting aperture. Since this deposit becomes thicker with continued operation of the microscope, the effects described above become greater. Finally, it is necessary to completely replace the aperture with a new one.

A similar type of trouble may be experienced if insulating particles of any sort become attached to the surface of the limiting aperture which is exposed to the electron beam. These insulating particles may drop off a specimen; they may enter the instrument through the air-lock, or they may be attached to a new aperture.

It is apparent, from the foregoing remarks, that it is absolutely essential that the limiting aperture be entirely free of any insulating particles or semi-insulating layers.

Preparation of the Objective Aperture—In order to avoid difficulty in the production of clean apertures, the following technique, as shown in Figure 17, has been developed, and, if followed carefully, should give the operator no difficulty.

These apertures are drilled by hand in small copper discs. The procedure is, in general, to drill a small opening with a specially ground needle and then to etch the opening until it is of the proper dimensions. A common sewing needle with a shank of approximately the same diameter as a common pin may be used for the

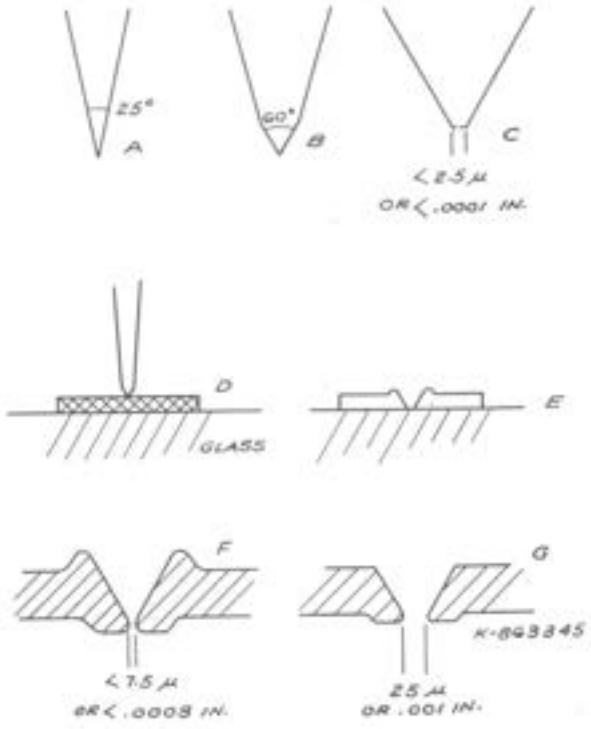

Figure 17—Preparation of Objective Aperture (K-863345—Sub. 0)

drilling operation. A convenient handle or pin vise may be used to grip this needle. Its point should be ground on a fine stone, such as a washita.

In order to observe the procedure a light microscope of about 100 power should be used, preferably with a calibrated scale. In the first stage of sharpening, the needle should be ground to a very sharp point with the cone of half-angle at about seven and one-half degrees. In the second stage of sharpening, the needle should be further ground into a cone of half-angle of approximately 20 to 25 degrees. The blunt end of the tip of the needle, as observed under the microscope, should be no more than from two and one-half to three microns in diameter. That is, it should be no more than one ten-thousandth of an inch.

It should be mentioned here that the sharpened needle should be cleaned very thoroughly by passing it through several layers of clean paper a number of times. It is preferable to pass the needle through the paper and then tear it out. That is, remove it without withdrawing the point backwards through the same hole. The needle should always be observed under a microscope to make sure that no dust or fibres, and, most important of all, no particles of the grinding stone appear on the point.

The holes are drilled in the copper blanks which are provided with the instrument. A disc should be placed on a clean glass surface and the hole is then drilled. The procedure here is to place the point of the needle carefully in the approximate center of the copper disc and to apply slight pressure while rotating the needle rather uniformly. Practice will indicate the amount of pressure and rotation required to puncture the proper hole, which should be about seven microns in diameter and reasonably circular. The copper disc with the drilled hole may then be immersed in a dilute nitric acid solution until the small end of the opening has a diameter of about 1 mil or 25 microns.

Here also, a little practice will indicate the strength of nitric acid solution to use and the length of time necessary to etch the opening to the right dimension. At this point the etched diaphragm should be taken out of the nitric acid solution and quickly dropped into some very clean distilled water in which the disc should be stirred around so that all the nitric acid is removed from its surface. A very clean pair of tweezers or forceps should be used for this operation. It is important that the distilled water used be fresh and extremely pure, preferably triple distilled. The diaphragm should then be removed from the distilled water and blotted between two sheets of a hard type of filter paper. The excess water will be immediately absorbed. It is important that no dust or loose fibres exist on the surface. The diaphragm should be placed on a very clean microscope slide and observed under the 100 power microscope. It should be very carefully studied by surface illumination so that any small particles of dust or paper fibres adhering to its surface may be observed. If there are any large fibres, usually they may easily be removed with a sharp needle. In the case of finer fibres adhering to the surface, it is better to discard the diaphragm and make a new one.

It is extremely important that the opening of the aperture be very close to a perfect circle. Strongly elliptical openings should be discarded. The finished diaphragm should be kept under a watch glass or some other dust cover until it is needed for use.

If the diaphragm has been kept for a long time before use, it is advisable to etch it slightly and repeat the above described washing and drying procedure before use.

The second step in the procedure is the mounting of this diaphragm in the holder in the objective assembly and its adjustment to such a position that the center of the opening coincides with the axis of symmetry of the whole lens. The old diaphragm should be removed from the aperture support assembly by removing the small assembly parts from the supporting tube. The plug may then be removed from the cap and the old diaphragm may be removed and discarded.

It should be noted that the aperture support assembly is supported in the objective lens pole-piece assembly by the threaded socket. To remove the assembly from the objective, it is only necessary to grip it and unscrew it to the left.

Before mounting the new aperture, it is essential that the outer surfaces of the cap be observed under a low powered microscope for adhering particles of dirt or signs of surface contamination. After several months to a year of use, it will be found that the inner-conical surface of the cap is coated with the same type of deposit as found right in the aperture itself. The simplest and most effective way of removing this is to use a small lathe to take a fine cutting from this surface and all the other outer surfaces.

After the aperture has been changed, the whole assembly may be screwed tightly back into the socket of the objective pole-piece. It is now necessary to center the aperture with respect to the pole-piece assembly. To facilitate this operation, the outside surface of the objective assembly was machined at the same setting as the other important surfaces of this lens system. The axis of this surface, therefore, exactly coincides with the axis of symmetry of the remainder of the system. To align the aperture, the objective assembly usually is set up on the stage of a standard microscope in the following way: The objective assembly is placed so that the aperture adjusting sleeve passes through the hole in the "V"-block plate and protrudes below the microscope stage. The horizontal position of the objective assembly is adjusted until the aperture can be seen through the microscope.

It is preferable to illuminate the system both from above and below. The eye piece should also have a cross-hair. The objective pole-piece assembly is now rotated in the V-block stand at the same time as the image of the aperture is viewed through the microscope and through the opening of the stand. It will be found, at first, that the aperture will follow a circular course, at the same time, turning about its own axis. The adjustment screws are adjusted in such a way as to move the aperture toward the center of its circular course. The process is continued until the aperture opening actually turns about its own center. When this position is reached, the adjusting screws should be all in a tightened condition.

It may be desirable to use some lubricant between the surface of the stand and the outside surface of the pole-piece assembly. In this case, very pure water or distilled alcohol should be used afterward so that no permanent film is left. Immediately after completing this operation, the pole-piece assembly should be either reinserted in the microscope or should be put in a dust-proof case until needed. To insert the objective pole-piece assembly in the objective ready for use, the reverse procedure of that used to take it out is followed. However, in placing the objective pole-piece assembly in the objective it is necessary that great care be taken not to jar the aperture support or do anything that might throw it out of center.

After the pole-piece assembly has been replaced and the plate of the specimen moving stage has been replaced and fastened by means of the two pressure springs, the specimen changing mechanism may be reinstalled (see page 52).

As in the case of changing a filament, the whole system may now be pumped out by connecting the whole microscope body to the auxiliary mechanical pump through one of the air-lock valve systems by turning the door clamp knob fully clockwise and, at the same time, leaving the inner air-lock gate open. As soon as a rough vacuum has been obtained in the whole microscope body, the door clamp knob may be turned to the neutral position which closes the connection to the auxiliary mechanical pump and the main valve may be opened so that the air may be exhausted through the diffusion pump and the main mechanical pump. Once again it is assumed that the main mechanical pump and oil diffusion pump have been left running during the replacement of the objective pole-piece assembly.

Realignment of the Microscope—After having replaced the objective aperture as described in the preceding paragraphs, the entire microscope may need to be completely realigned. A systematic alignment procedure has been described on pages 39 to 41 to which reference should be made here. The microscope should also be realigned after standing idle for any great length of time, or after replacement of the filament.

Centering of Specimen Stage (for stages with remote motion controls)—The specimen stage within the specimen chamber may be moved in the horizontal plane by means of two position controls mounted at right angles to each other. Each of these is connected through a worm gear and flexible shaft to a control knob installed on the instrument shelf. By adjusting these two knobs, the specimen stage and specimen holder may be displaced horizontally in any desired direction. Each of the controls is provided with a pointer and graduated scale mounted on the specimen chamber. The full range of the scale corresponds to a 25-mil displacement of the specimen.

Centering Control Adjustment—Proper adjustment of the centering controls is obtained as follows:

a. Remove the main valve from the specimen chamber. Remove also the pointers and graduated scale cover plates from the centering controls on the specimen chamber.

b. Insert the centering pin (item 15-H on M1-12955-D) in place of the specimen holder.

c. Rotate the two centering controls, while observing the centering pin, until this drops down into the top of the plate. The specimen stage is thereby centered correctly.

d. Remove the centering pin. Replace the covers on the centering controls. Replace the pointers on the control shafts, setting the pointers to mid-scale position. Replace the main valve on the specimen chamber.

Centering of Specimen Stage (for stages with differential motion screws)—The centering procedure described above relates to equipments which are provided with remote controls. In earlier equipments, the controls are operated from knobs mounted directly on the specimen chamber, and the centering procedure applicable to these equipments is set forth below:

1. Enlarge the hole nearest the center of a standard specimen screen with a pointed tool. This provides a means for observing "centering" as described later.

2. Place the special screen in a specimen holder in the high magnification position.

3. Remove the specimen chamber main valve assembly and seal the orifice with a rubber cork or combination clamp plate and gasket. Pump down microscope.

4. Remove specimen control shaft knobs by loosening Allen set screws.

5. Remove specimen limit travel screws (L. H. Thread) from center of threaded bushings.

6. Remove threaded bushings (R. H. Thread).

7. Slip one of the threaded bushings on the shaft of the "stage centering" tool. (This tool is about six inches long, has one end threaded for ¼ inch with an $\frac{8}{32}$ L. H. Thread, has a round body 4 inches long ¼ diameter and a handle at the other end 1½ inches long, knurled or shaped for gripping and operating.)

8. Thread stage centering tool into one of the sylphon assembly stems.

9. Slide threaded bushing forward on stage centering tool and thread bushing into bushing seat, for the distance of a few threads. During this operation press forward gently on the centering tool to prevent the bushing threads from engaging the threads of the sylphon assembly stem.

10. Repeat operation #9 for the remaining bushing and sylphon assembly.

11. Provide electron beam, and observe intermediate image. Reduce objective current until from six to eight specimen screen holes are visible.

12. Adjustments #9 and #10 are continued until the specimen screen reference hole falls on the center of the intermediate screen.

13. Back off each bushing not more than one turn.

14. Using centering tool again, gently pull each sylphon assembly towards its respective bushing, at the same time rotating the bushings clockwise so that the threads of the bushings and sylphon stems "make-up".

The above procedure should align the specimen stage and the specimen control screws properly.

Overload Relay, Adjustment Procedure—The function and operation of the overload relay are described on page 39. The following adjustment procedure relates to the latest type relay (Stock No. 47477) as supplied with the new Type EMB-4 Electron Microscope. These relays are carried in stock and are available as replacements for the older style used on all previous types of EMB microscopes. A photograph of the overload relay is shown in Figure 50, to which reference should be made in connection with the following description of the relay adjustment procedure.

Caution—Adjustments 1, 2 and 3 below should not be necessary under normal conditions of usage and wear. Adjustment 4 may be necessary if contact pressures become unequal. Adjustment 5 sets the "pick-up" and "drop-out" currents and such adjustment may be necessary at time of installation. In general, adjustments should be made in the order listed, **if necessary.** For example: If adjustment 2 is necessary, adjustments 3, 4 and 5 should be checked and readjusted, if necessary, **after** adjustment 2 is made.

1. **Closed Air Gap Adjustment:** With the relay armature in closed position, adjust the anti-freeze pin by inserting a .005" feeler gauge between the relay armature and the edge of the pole face nearest the hinge while turning the pin clockwise to open the gap, or counter-clockwise to close the gap until the gauge just clears. Then set the lock nut on the anti-freeze pin.

2. **Open Air Gap Adjustment:** With the relay armature in open position, adjust the armature limit pin by turning the pin clockwise to close the gap, or counter-clockwise to open the gap until a .012" feeler gauge between the pole face and anti-freeze pin will just clear. Then set the lock nut on limit pin.

3. Adjust the contact gap with the relay armature open by turning the N. C. (normally closed) contact pin clockwise to close the gap, or counter-clockwise to open the gap until a .015" feeler gauge between the contact armature and N. O. (normally open) contact will just clear. Set the lock nut on N. C. contact pin.

4. To obtain equal contact pressures on both the N. C. and N. O. contacts, turn the contact pressure adjusting screw clockwise to decrease N. C. contact pressure and increase N. O. contact pressure. Similarly, to increase N. C. contact pressure and decrease N. O. contact pressure, turn the contact pressure adjusting screw counterclockwise. Set the lock nut, taking care that the adjusting screw does not turn.

If the contact arm does not leave either the N. C. or N. O. contacts when the relay armature is opened or closed, the approximate setting of the contact pressure adjusting screw may be determined as follows:

(a) Turn the contact pressure adjusting screw counterclockwise until the N. C. contact will not open when the relay armature is closed. Hold the relay armature closed and turn the contact pressure adjusting screw clockwise until the contact arm snaps into closed position. **Mark the position of the adjusting screw.**

(b) Continue turning the contact pressure adjusting screw clockwise until the contact arm remains in closed position whether the relay armature is open or closed. Then, with the relay armature open, turn the contact pressure adjusting screw counter-clockwise until the contact arm snaps into open position. **Mark this position of the adjusting screw.**

The approximate setting of the contact pressure adjusting screw for equal contact pressures and equal wipe on each contact is midway between the two points (a) and (b) above.

5. Final adjustment of pick-up and drop-out current values is obtained by turning the elastic stop nut on the relay armature compression spring. To increase pick-up current and decrease drop-out current, turn the nut clockwise. Turning

the nut counterclockwise decreases pick-up current and increases drop-out current.

6. The relay must operate on .70 to .75 ma. After operation, the relay must drop-out on .20 to .30 ma.

7. The pressure between the contact arm and either contact must be 4+ grams.

Replacement of Coating on Fluorescent Viewing Screens—A new fluorescent material, ZnS-CdS-2272 (1-oz. bottle Stock No. 47656) is now available for coating screens used in the Electron Microscope. The material has a brilliant yellow fluorescence, is light yellow when viewed by daylight, has a finer particle size than the standard Willemite formerly used and produces three times the visible light given off by Willemite under the same electron bombardment. The color excited is in the region of greatest sensitivity of the eye.

Preparation—ZnS-CdS-2272 comes in the form of a fine powder which must be suspended in a volatile solvent for coating. It is recommended that 1 oz. of the material be suspended in 8 oz. of a 50-50 mixture of ethylene dichloride and dioxane. This mixture must be stirred well in order to break up agglomerates of the fine particles. Ten minutes agitation in a Waring Blender or thirty minutes with an ordinary laboratory stirrer should be sufficient. If the "settling" technique described below is preferred, the ethylene dichloride-dioxane solvent is satisfactory. However, if the spraying technique is employed, acetone or amyl acetate provide very satisfactory action. The inclusion of a small amount of 2% parlodion solution (2% parlodion in amyl acetate as commonly used for specimen supporting films) tends to make the phosphor adhere more securely.

Application—The simplest method of coating the surfaces is to use a spray gun. A kit that has been found satisfactory consists of the following parts obtainable from the DeVilbiss Company, Toledo, Ohio:

1 Type CH-502 Spray Gun with type C-625 cap
1 #90 Air Cap
1 #902 Air Cap
1 Type H Fluid Cap
1 Type F Fluid Cap
1 Connection H-601
10 ft. tubing type H1080
2 C-625 Cups (6 oz. glass)
1 Type C Suction Cup Feed Attachment

These components permit a wide range of spray control, and the best combination for use can be found by experiment.

It is essential that the compressed air used to operate the spray gun be free of oil, water, and dust, as contamination of the fluorescent material seriously affects its performance. A Cenco Oil Separator and Air Filter #1395M or equivalent should give good results when inserted in the air line.

The best distance at which to hold the gun when spraying a surface is determined by the air pressure used and the rate of evaporation of the solvent. If the gun is held too close to the surface, droplets will form and a non-uniform coating will result. On the other hand, if the gun is too far away the solvent will evaporate too soon and the coating will not stick. A little practice will permit the correct technique to be determined.

If a finer, more uniform coating than can be obtained by spraying is desired, the surface may be covered by allowing the fluorescent material to settle on to the screen. For this process, the screen should be placed in an evaporating dish which is equipped with a stop-cock in the bottom. The well-dispersed suspension is then poured in, the dish covered, and the stop-cock opened so that the liquid may drip out slowly. A very uniform coating of small particles and concomitant high resolving power may be obtained in this manner. Such a coating is required only for the final viewing screen, however, as high resolution is not essential for the intermediate or gun screens.

As **thin** a layer of ZnS-CdS-2272 as practicable should be used on the gun and intermediate screens. The metal should still be visible through the coating. If too much of the phosphor is used, serious optical difficulties will arise because of the considerable electrostatic charge built up by the material. The final viewing screen should have a heavier coating, as it must be adequately covered in order to provide sufficient intensity and detail. However, an adequate coating is one which is **just sufficient** to completely cover the metal surface. **Too heavy a coating may result in image distortion.**

Care of the Diffusion Pump—A brief description of the oil diffusion pump was given on page 18.

For the satisfactory operation of the pump, it is essential that there be sufficient oil in the boiler (about 115 gms.) and that the oil be fairly free from contaminating materials. Furthermore, the components of the jets must be in good alignment and the bottoms of the chimneys must rest in their respective grooves in the base of the pump.

The diffusion pump should be dismantled, emptied of oil and thoroughly cleaned with an oil solvent (carbon tetrachloride is not recommended) **at least once a year.** If at any time between regular cleaning periods the pumping time necessary to obtain an operating vacuum should increase appreciably, or if an operating vacuum should be unobtainable, the pump should be checked and cleaned if necessary.

In order to check the condition of the pump, the pump must first be stopped and filled with air. Then, remove the cover of the side arm directly below the manifold valve handle. The side arm

consists of a tube within a tube. In the lower part of the outer tube collects a portion of the oil which distills over. This should be removed with a pipette, measured, and its color noted. If a quantity greater than 10cc of oil is found, or if the distillate is dirty, the pump should be dismantled and cleaned.

The procedure in this case is as follows:

First, remove all batteries from the battery box. This is most important as contact with internal wiring is unavoidable in removing the Diffusion Pump, and the voltage is sufficiently high to give a fatal shock.

The microscope table and base covering should be removed, and the thermocouple tube taken off. To free the pump from its mounting, the eight screws which connect the upper side of the pump to the lower flange of the valve are removed and the gasket clamp is loosened. Then, by working through the large opening in the microscope pedestal, the screws which hold the supporting brackets for the pump in place may be taken out. This allows the pump and bracket to be lowered so that the pump and bracket may be completely removed from its mounting. During the removal of the pump, care should be taken that it is not inverted. The inner assembly should be removed by lifting it out through the top.

The oil should now be poured out and the pump left inverted for a considerable time so that any remaining oil may drain out. After the oil has drained out, the whole pump should be flushed with a solvent. The inner assembly should also be washed with the solvent. Clean, dry air should then be blown through the pump from the top and through the side arm until no vapor of the solvent remains. Then the chimneys should be replaced carefully so that the bottom fits into the grooves in the base of the pump. If the positioning is incorrect, the pump will not operate satisfactorily. The pump should be refilled with 115 gms. of Octoil. In filling, the oil should be poured down the wall of the pump so that none of it is splashed on the upper part of the jet system. Without being inverted, the pump should then be immediately reinstalled in the microscope assembly.

An alternative method is to reinstall the pump dry, and then pour the Octoil into the boiler through the center tube of the sidearm. A clean funnel should be used and the oil must be poured slowly so that none overflows into the outer tube. The side and cover should then be replaced and pumping started.

It will be found that on the initial pumping, low pressures will be obtained much more slowly with the fresh oil. Moreover, when the heater of the pump is turned on for the first time, it will be noted that the pressure actually increases as shown by a decrease in the reading on the "THERMOCOUPLE" meter. This effect is due to the expulsion of gases which are trapped in the oil. After a few hours of operation, these gases will be eliminated and from then on the pump should act normally.

Checking for Vacuum Leaks—Systematic Procedure—Following the preceding general remarks, a systematic procedure is given below which will facilitate the location of leaks. A diagram of the entire vacuum system including pumps, valves and gauges as well as the implied functions of each is shown in Figure 9, page 21. The technique of leak hunting and trouble shooting can be made faster and much labor avoided if this vacuum system diagram is kept in mind and used as a step by step guide for trouble isolation.

The thermocouple and ionization gauges provide valuable assistance in locating leaks or other defects. For instance, a small leak or one which does not impair thermocouple readings but which is evident on the ionization gauge can be located more easily if the vacuum system is adjusted as follows: The main valve is turned until it is almost closed. A critical point will be found where any further closing of the valve will cause the ion current to rise rapidly. This critical point provides greatest sensitivity for leak searching technique, and is the point at which, neglecting occluded gases and other factors, the rate of evacuation is in equilibrium with the rate of air leak.

The effectiveness of the main valve critical point technique is limited by the inherent lack of sensitivity of the thermocouple gauge and the physical location of this gauge in the vacuum circuit, on the pump side of the main valve. If pressures lower than those corresponding to galvanometer readings of 60 cannot be obtained, a sizable leak is indicated. Generally, if galvanometer readings reach 60, they will continue to rise to about 95. This continuous rise is explained as follows: A galvanometer reading of 60 indicates the critical pressure at which the diffusion pump commences functioning. Since the diffusion pump evacutes 40 or 50 times faster than the mechanical pump, the outgassing rate in the region from 60 up is much greater than the leak rate, for so small a leak which permitted the pressure to become as low as 60. Equilibrium is generally reached at a reading of about 95. The thermocouple gauge is most sensitive in the range of galvanometer readings of from 60 to 95. However, since the thermocouple readings are dependent on thermal phenomena, the response in leak tracing operations is slow compared to that of the ionization gauge.

Where it is fairly certain that a small leak is confined to a known section of the Microscope, castor oil can be applied sparingly to the various parts of the isolated section until the leak is covered, at which time the gauge or gauges being used will indicate a decrease in internal pressure.

A common and practical method of testing for small leaks involves the use of a 4-oz. atomizer filled with ether. All joints and surfaces are sprayed until there is an indication that the internal pressure has increased. Ether, having a high vapor pressure, seeps readily through the perforation fault, and gives an immediate indication of increased pressure. Hydrogen gas is as effective as ether, but is not generally as easily available and involves explosion hazards unless severe caution is exercised. Acetone is also an effective substitute for ether but unfortunately it is a solvent for the baked-on finish of the Microscope.

Large leaks, such as those which do not permit pressures less than galvanometer readings of 60, most generally have to be found by dismantling the Microscope section by section until the offending part is isolated. As each section is removed, the exposed openings of the intanct column must be temporarily sealed and the vacuum test process continued. Temporary seals can be made from thin pieces of neoprene or sulphur-free rubber sheets held in place over the exposed openings by the weight of suitable metal discs or cylinders or a combination of them. After isolation, the perforation fault of an offending section can be readily found by one of two methods: In the first method, the section is sealed off by means of clamps, gaskets and gasket plates, with the exception of an orifice where air pressure (2 or 3 lbs.) can be introduced. The bubble stream appearing when the section is submerged in alcohol with the air pressure applied, gives an immediate clue to the source of the leak. Alcohol is used because of its low surface tension and freedom from trapped gases in the form of bubbles. In the second method, the same procedure is used except that, instead of alcohol immersion, the section is painted with soap bubbles. The source of the leak, of course, is the point at which new bubbles are constantly appearing within the lather.

As an alternative to the step-by-step dismantling routine, the soap-lather and pressure method may be applied to the entire vacuum column. Air pressure can be introduced easily by means of a hand pump and hose fitting attached to the auxiliary pump feed line where it enters the camera chamber. The rubber hose feed line is disconnected during the procedure. The hand pump and hose fitting should include an ordinary tire valve to prevent the compressed air from leaking back through the hand pump. In some cases, leak isolation by the above method may save considerable time over the step-by-step dismantling routine because the chances are that fewer individual sections will have to be disassembled and reassembled.

In all cases, use of the various control valves may shorten the leak searching time considerably. Examination of the vacuum system diagram shows how various sections of the Microscope system may be eliminated as the sources of trouble. The main valve can isolate the leak to the pumping system alone or to the main column, or it can point to itself as the cause of the trouble. The camera and specimen chamber valves can provide similar leak isolation for their respective chambers but are not capable of isolating themselves as trouble sources.

In dismantling and reassembling the Microscope vacuum system, there are a few "don'ts" which are of considerable importance. First, don't remove screws, washers, gaskets, etc. without marking them carefully so that they are returned to their original positions. Do not permit the points where Picein wax is used as a seal (top of electron gun, glass shell of electron gun, thermocouple gauge) to be handled roughly, or the wax will crack and cause a leak. Don't allow gasket seats to be marred or damaged as leaks are apt to result. Do not expose the Microscope interior or inner parts to atmosphere and particularly to dust for any longer a period of time than absolutely necessary. Dust particles, lint, etc., can pick up electrostatic charges from the electron beam and seriously interfere with the quality of the final image. This is particularly true of dust particles which settle on the apertures or on the inner configuration of the pole pieces. Electrostatically charged foreign particles can cause the final image to move continually or to oscillate. These phenomena, however, are distinct from image drift caused by electrostatic charges taken up by certain types of specimens and for which, at this writing, there is no certain cure.

When reassembling a Microscope system, in which some parts have been subjected to water, alcohol or other substances, it will be found that the pump-down time to remove gases may take an hour or longer. However, from this point on, provided that the system is tight and no further contamination other than routine is permitted, the pump-down time will shortly reduce to a point where, with a hot diffusion pump and with the camera chamber isolated, not more than 5 to 10 minutes will be required to reach operating pressure from a standing-still sealed-off period of 12 hours.

Soldering Procedure—The following soldering procedure is particularly applicable to the repair and installation of sylphons.

a. All surfaces requiring tinning must first be cleaned. Fine sandpaper and a solvent may be required.

b. Use zinc chloride as flux. Do not permit any other flux to come in contact with the work. Keep soldering iron free from any other type of flux.

c. **Immediately** after tinning operation, thoroughly remove all traces of flux with hot running water.

d. Tinned surfaces, which are to be joined to others, should not be left unassembled for more than 24 hours.

e. When sylphons attached to parts having large heat capacity must be replaced, it is convenient to heat the entire assembly on a hot plate until the old solder melts. The damaged sylphon can then be removed easily and the new one installed. While the parts are still hot, a soldering iron should be used to smooth the seal and make a vacuum tight joint.

f. Wherever possible, flux should be avoided when assembling or joining parts with tinned surfaces.

g. Where flux may be required in Item f, resin is recommended as the flux. All traces of resin should be removed with alcohol after solder operations.

h. It is advisable to paint any new sylphon with a thin coat of glyptal lacquer (General Electric #1202 glyptal and #1500 thinner) after it has been soldered and before installing it in the microscope. This procedure serves the double purpose of inhibiting corrosion and sealing any pinholes in the body of the sylphon or soldered joints.

Touch-up Enamel Kit MI-7443—Under this title is comprised a kit including the various paint finishes used on the Electron Microscope. The kit is made up of the following items:

1. One 1-pint can of enamel, Fin. No. 540 (silver gray).
2. One 1-pint can of enamel, Fin. No. 685 (umber gray).
3. One 1-pint can of enamel, Fin. No. 686 (deep umber gray).
4. One 1-quart can of thinner, RCA No. 3.
5. One packing list.

Item 1 (Finish No. 540) is employed on the interior of the cabinet and other inside parts. It is applied after diluting one part of the No. 540 finish with one part of RCA No. 3 thinner (item 4 above). The thinner is highly inflammable and should not be used near an open flame. Sufficient ventilation must be available at all times during its use.

Items 2 and 3 (Finishes Nos. 685 and 686) are applied on the microscope column and outer cabinet surfaces. They are used with one part of RCA No. 3 thinner for the first or prime coats. For second or touch-up coats, the Nos. 685 and 686 finishes may be used without thinner.

For best results, Finishes Nos. 540, 685 and 686 may be sprayed in covering large areas. Small areas and marred surfaces can be touched up with a soft brush.

All outside finishes can be protected and improved through application of Simoniz wax or equivalent.

THE PREPARATION OF ELECTRON MICROSCOPE SPECIMENS

In the type of electron microscope which has been described in the preceding pages, the specimen is viewed by transmitted electrons only. The ideal type of electron microscope specimen is one in which the relative differences in density and thickness are a maximum. Moreover, for ideal observations of internal structure, the thickness of the specimen should not be more than one-tenth of a micron and no part of a specimen should be more than one micron thick. This means that, in general, the specimens which are most suitable for observation by the electron microscope are those which fall beyond the resolution of the light microscope, though excellent results can be obtained with a few particular specimens which are quite large.

The types of specimens which have been observed with the present type of electron microscope should be roughly divided into four different groups. In reality, these groups form a fairly continuous range, but the techniques which are applied in order to obtain the best results differ considerably over this range.

TYPES OF ELECTRON MICROSCOPE SPECIMENS

Molecular—This type of specimen includes the study of the structure of certain materials for the purpose of actually seeing the molecules, and includes such materials as plastics, synthetic films, cellulose and a number of the large protein molecules. The investigation is usually carried out as an examination of a thin film of the material itself or a deposit of the material on a thin structure—less film of collodion.

Colloidal—Placed intermediate to the preceding and the present groups there should be, perhaps, a connecting group of materials such as the viruses which are supposed to be extremely large protein molecules. The dimensions, however, lie in the domain of what are usually known as colloidal particles. True colloidal particles are represented by such industrial materials as carbon black, pigment, emulsion, photographic emulsion, clays and a whole large group of finely divided chemicals of all kinds. This type of specimen is usually prepared either by dispersing the colloidal substances in the material from which a supporting film may be made, or by depositing it on the surface of a prepared collodion film by liquid dispersion or by chemical deposit directly on a film or on the edges of the openings of a metal screen. The examination by the electron microscope provides a very rapid and accurate check on two of their most important properties, namely, their size and shape.

Structural—The previous groups involve particles which are considered as being homogeneous in themselves. Owing to their dimensions it is reasonable to believe that any structure that ex-

ists in an individual colloidal particle is molecular in nature; that is, the structure is that of molecular arrangements and of the molecules themselves. However, when one considers the domain of slightly larger particles and, in particular, the domain in which organisms that are definitely living begin to appear, one expects to encounter a much more complicated type of structure. This type of structure comprises the localization of different chemicals and reaction into domains which are themselves of colloidal dimensions. This group includes such specimens as bacteria and the crystal form of industrial chemical products. It may also be considered as including a great number of biological structures of the same dimensions. The specimens are usually prepared by methods already mentioned in connection with colloidal specimens.

Contour—This group includes a few specimens which are, in general, very large, but which have associated with them some property which enables useful information to be obtained by observation in the electron microscope. Such information is always in the form of a micrograph of the contour of the interesting part. This group includes such large particles as large size powders, diatoms, razor blade edges and parts of bearing surfaces. The mounting technique for this type of specimen is usually one of mechanical fastening.

In the above, it has been pointed out that the maximum specimen thickness permissible for best resolution is extremely small. It is apparent from this, that the problem of providing a suitable support for the specimen is one of the major difficulties. The ideal condition is, of course, when the specimen is self-supporting and the electron has to pass through no material other than the specimen itself. Unfortunately, a great majority of specimens cannot be studied in such a form and must be mounted upon a supporting film which in itself produces a minimum effect on the incident electron beam.

The fundamental properties which are required of such a membrane are:

(a) It must be strong enough to support its own weight over relatively large openings even though it be only a few atoms in thickness.

(b) It must be strong enough to stand the weight of a reasonable amount of a specimen and also to withstand some of the surface tension effects which are encountered in the handling and preparation of the specimen.

(c) It must be of light material and thin enough so that the electron image produced is not appreciably different from the image produced of empty space.

(d) It must appear absolutely homogeneous and structure-less to the electron beam.

(e) Finally, it must be able to withstand an intense electron bombardment without being ruptured.

Such properties have been found in a number of types of organic membranes. These include membranes made of collodion, gelatine and some varnishes such as "Formvar".

METHODS OF PREPARATION OF THE SUPPORTING MEMBRANE AND THE SPECIMEN ITSELF—For the preparation of the thin membrane three different methods have been developed.

Casting—In this method the materials from which the membrane is to be made is dissolved in a volatile solvent. A drop of this solution is placed on the surface of a suitable liquid. A satisfactory choice for this liquid is one in which neither the membrane material nor the solvent will dissolve, and one which has a higher surface tension than the solution. When a drop of the solution is placed on the surface of the liquid the difference in surface tension allows the drop to spread over a considerable area. This exposes a large area to the air thus allowing the solvent to evaporate quickly, leaving a thin solid film on the surface of the liquid. This film may then be mounted by the method described below.

Dipping—This method is particularly applicable to the observation of the structure of the films themselves. It consists of merely dipping the screen specimen holder into a dilute solution of the material, removing it and allowing it to drain and to dry. After the concentration of the solution has been properly adjusted and the process carried out in a standardized manner, it is possible to produce, across the opening of the specimen holder, extremely thin films suitable for observation with the electron microscope.

Stripping—This method was first developed for electron diffraction work. A solution of the materials from which the membrane is to be made is coated on the surface of a specially cleansed piece of glass. Once again the solvent used must be volatile. Before the solvent evaporates, the thickness of the layer on the glass is made extremely uniform by spreading the solution by means of a special gauge. This gauge usually consists of a razor edge mounted so that when it is passed over the glass surface there is a constant spacing between the edge and the surface of the glass plate. This thickness is adjusted so that when the solvent evaporates, a solid film of the desired thickness will be left on the surface of the glass. A heavy frame of the material is then painted around the thin film area so that a fairly substantial edge is provided which helps in the stripping process. The latter consists of loosening one side of the thick edge of the film and lowering the glass plate obliquely into clean water, film side up.

If the glass and water surface have been properly cleansed, the film will float off onto the surface of the water. It may then be mounted by one of the methods described below.

In the following description of the various types of preparation technique, the method by which the preparation is mounted on the screen specimen mount will be mentioned. However, owing to the extreme importance of one of these methods this will be described in detail. This method will be referred to in the following as the mounting of a cast film. In particular, the type of film prepared will be collodion.

A well-filtered solution of collodion in amyl acetate (2% collodion) is drawn up into an eyedropper and a single drop placed carefully on the surface of well-distilled water. For the concentration of the solution mentioned above, the water surface should be at least 20 centimeters in diameter, preferably circular, while the drop size should be of the order of 1.5 millimeters in diameter. On reaching the water surface, the drop spreads over a fairly large area and the amyl acetate evaporates leaving the desired film of collodion floating on the surface of the water. During the process of spreading and evaporating, interference colors can be seen in the film and can be used as a check on the quality of the film to be obtained. Such interference colors should appear either uniform over the whole of the surface of the film or in fairly uniform broad circles. In the last stages of drying, the thickness of the film is much less than the minimum which will give interference colors. However, when the drying is completed, the remaining film may be detected by a difference in the sheen of the water surface. Moreover, a good film appears to be surrounded by a very narrow corrugated edge. The edge of the film should, of course, be approximately circular if the spreading took place uniformly. By measuring the diameter of the film on the surface of the water, it is possible to calculate the thickness if the size of the original drop and the concentration of solid material in that drop are known.

After a film has been obtained on the surface of the water, a number of screen discs are placed around the surface. These are picked up in the circular loop from below. In order to leave all of the film except the part being used undisturbed, a needle is run quickly around the edge of the loop thus cutting out that portion of the film. As it is lifted out of the water, the wire loop carries the screen disc supported in its opening on the collodion membrane and a certain amount of water which still adheres to the lower side of the membrane and the loop. This is inverted and passed over one of the small cylinders. A pair of forceps is now used to lift the cylinder up through the loop so that the latter may be taken off the bottom. After this operation, the screen disc rests on top of the cylinder and is completely covered by the collodion membrane upon which there is usually adhering a few drops of surplus water. The surplus water is then drawn off immediately by means of a micro-pipette. As water does not readily wet collodion, the extra drops of water drawn off by the above method come off very completely and take all foreign material either in the water or on the surface of the drop with it. The specimen mount is then ready for the addition of the specimen, or, if the preparation is of the kind where the specimen is imbedded directly in the collodion itself, is ready for observation in the electron microscope. Films prepared in this way have been found to be extremely clean and do not possess any structure of their own.

Alternate Method for Screen Film Preparation—An alternate method for preparing the screen films is described below. This is simpler than the method set forth in the preceding paragraphs, and does not require any special tools to be used.

a. In the same manner as explained in the first column of this page, prepare a thin film of collodion on the surface of well distilled water contained in a vessel at least 20 centimeters in diameter. The vessel should be filled with water up to a level of about three to four inches.

b. Place 6 or 8 screen discs on the film surface along two parallel rows. The discs in each row as well as the two rows themselves should be about ¼ inch apart from each other.

c. With a clean tool, gently press down each disc so that the collodion film will adhere to the screen mesh of the discs.

d. Taking a very clean microscope slide, hold this vertically over the surface, with one of the small edges at the bottom, about ¼ inch from the end of the two rows of discs.

e. Then move the slide downward into the water. The collodion film on the water surface will thereby be pushed down, fold up around the bottom edge of the slide, and apply against the face of the slide, to which it will adhere. The screen discs, in this manner, find themselves between the face of the glass slide and the collodion film.

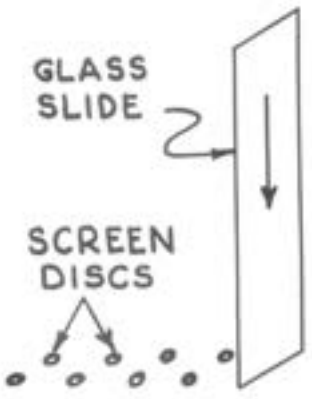

Figure 18—*Screen Film Preparation* (*K*-885394—*Sub.* 0)

f. Pull the slide upward vertically out of the water, drain off the excess water by holding the bottom edge of the slide against a clean piece of cloth or blotting paper. Then allow the slide to dry about 5 minutes.

g. The collodion coated screen discs may now be removed from the slide, and are ready for use.

DESCRIPTION OF A NUMBER OF TYPES OF ELECTRON MICROSCOPE SPECIMENS—The following is a detailed list of the types of specimens which have been used in connection with the application of the electron microscope to various fields. Each of the types of specimen described is represented schematically in Figure 19, where the numbering corresponds to the numbering in the list below.

1. **Single Film**—In this example, it is the film itself that is to be examined. Such films are usually prepared by either the casting or stripping method and are mounted on the specimen screen by some method comparable with that described above.

2. **Supporting Film Plus Deposited Particles**—This is the most common type of electron microscope specimen preparation. Here a thin structureless membrane is prepared and mounted on a screen disc by some method comparable with that described above. After the mount has been completed, the material to be examined is added to the surface usually in the form of a dispersion in a volatile liquid medium. A small drop of this dispersion is placed on the membrane and the dispersing agent allowed to evaporate.

A number of colloidal materials and biological specimens such as pigments and bacteria can be examined by this method. It should be mentioned at this point that the specimen is always added to the side of the screen disc bearing the supporting membrane. In other words, on passing through the complete specimen the electron passes first through the opening in the screen, then through the supporting membrane and finally through the specimen itself before entering the objective lens.

3. **Supporting Film Plus Particles in a Cast Film**—In the preceding example, difficulty is sometimes encountered in keeping the particles to be examined well dispersed throughout the final stages of the drying process. If the degree of dispersion obtained is of greater importance than the actual nature of the particles themselves, the specimen may be prepared in a different manner. In this method, the particles are dispersed in some agent which is not volatile and which, moreover, may be spread on the surface of some liquid in much the same way as the collodion solution in the formation of the supporting film. An example is the dispersion in a type of oil which can be spread in the form of an extremely thin film on the surface of water. Such a film may be transferred to a prepared specimen mount by carrying through the technique described above in connection with the preparation of a collodion film. However, in this case a specimen screen which has already been provided with a supporting film is used.

4. **Supporting Film Plus Evaporated Material**—A very interesting type of specimen for the electron microscope is the one which may be produced by sputtering or evaporating a thin metal film on the surface of a supporting film.

5. **Supporting Film Plus Dry Material**—The material to be examined by the electron microscope is often in the form of a powder, the properties of which do not permit it to be put in the form of a suspension. Examination of this type of specimen can only be carried out with a dry preparation. Such material may consist of extremely fine particles, which usually tend to clump. When these are dusted on the surface of a supporting film they form a relatively uneven layer which is quite loose and easily scattered by the repulsion effect of electrons absorbed by any of the particles. Such particles when dropped into the objective aperture may cause many difficulties. In order to avoid such difficulties, a second collodion membrane is usually placed over the loose particles in such a way that the particles are prevented from dropping off the specimen. This of course leads to a decrease in the resolving power obtainable due to the spatial scattering in the second film.

6. **Supporting Film Plus Second Film**—Often when observing various types of membranes with the electron microscope, one encounters films which may be formed in one of the above methods but which are not strong enough to be self-supporting over the openings of the screen specimen mount. To overcome this, it is usual practice to mount the film to be observed on an extremely thin supporting film.

7. **Specimen Included in the Supporting Film**—A second common method of preparing electron microscope specimens is that in which the particles of specimens to be observed are contained within the supporting film. In the case of inorganic chemicals, it is usual to disperse them in the collodion solution used for forming the regular supporting film. As this solution is an exceedingly good dispersing medium, the method may be applied to a very large number of materials. It has a possible disadvantage due to the fact that each particle is coated with an extremely thin film of collodion. However, the difference in density between the particles to be examined and the material of the supporting film is usually sufficient to enable an exact interpretation of the picture to be made.

A variation of this method is found in the use of the dipping method of preparing the specimen.

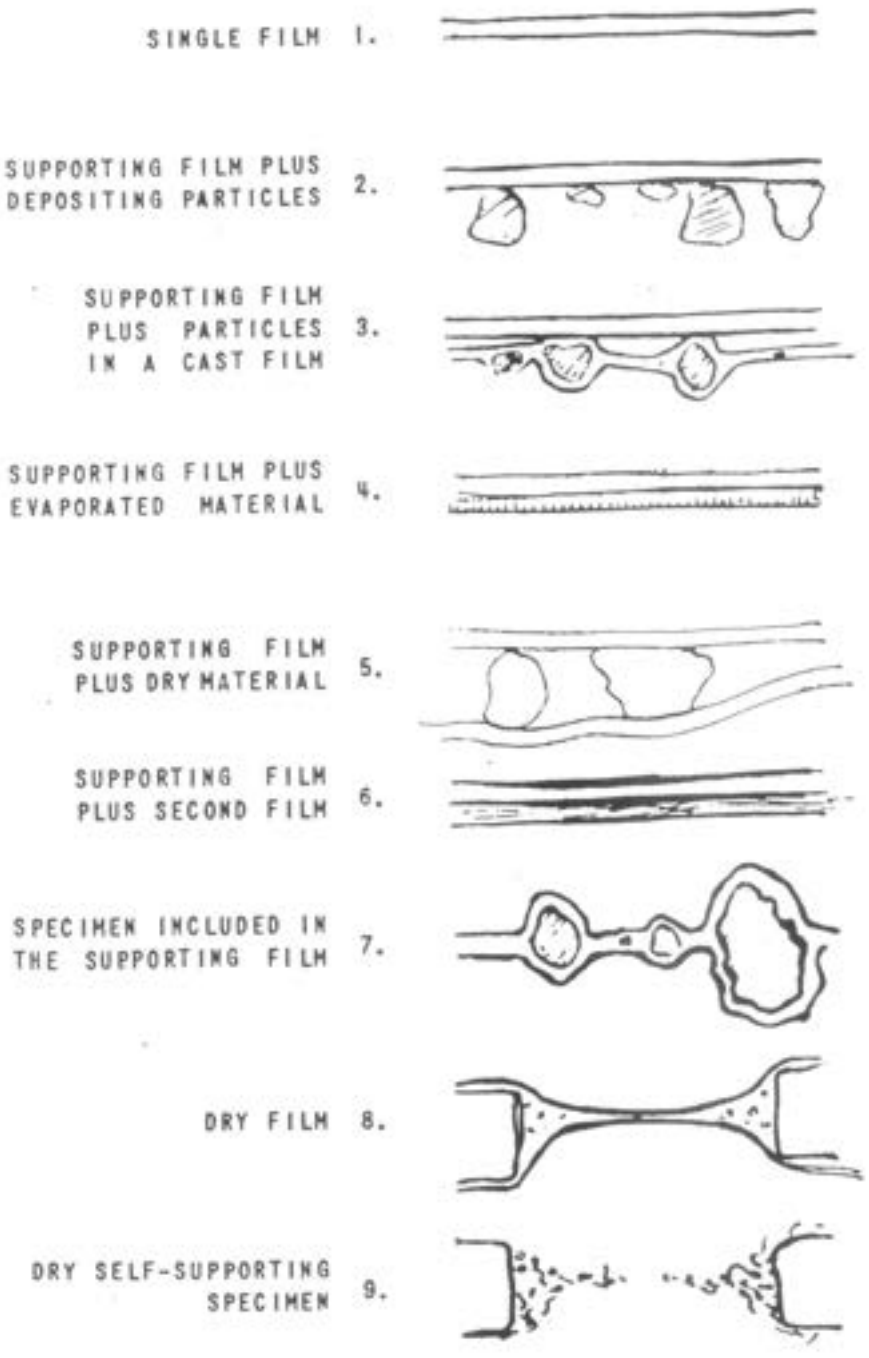
SINGLE FILM 1.
SUPPORTING FILM PLUS DEPOSITING PARTICLES 2.
SUPPORTING FILM PLUS PARTICLES IN A CAST FILM 3.
SUPPORTING FILM PLUS EVAPORATED MATERIAL 4.
SUPPORTING FILM PLUS DRY MATERIAL 5.
SUPPORTING FILM PLUS SECOND FILM 6.
SPECIMEN INCLUDED IN THE SUPPORTING FILM 7.
DRY FILM 8.
DRY SELF-SUPPORTING SPECIMEN 9.

Figure 19—Preparation of Electron Microscope Specimens

In this case, the particles to be examined are also dispersed in the original solution but instead of casting or stripping, the film is prepared by dipping the screen disc in the solution, draining and allowing to dry so that a thin membrane is left suspended across the opening of the mesh. This variation of the method is most useful in the case of organic or biological material, since one of the most suitable film materials for this type of preparation is gelatine.

8. **Dry Film**—This method consists of preparing specimens by the dipping method where the material used is the one to be examined. It is particularly applicable in the case of soaps and the structure of such materials as gelatine.

9. **Dry Self-Supporting Specimen**—A group of specimens may be prepared by passing a screen disc through an atmosphere of the material under such conditions that some of it will adhere to the edges of the openings of the screen. They can then be examined by the electron microscope. The method may be applied to the various types of smokes from flames or arcs.

PROBLEMS ASSOCIATED WITH THE PREPARATION AND OBSERVATION OF ELECTRON MICROSCOPE SPECIMENS—In the above description of the types and preparations of electron microscope specimens, it has been indicated that there are a number of difficulties which must be overcome in order to obtain a successful electron micrograph of any particular material. The first of these includes those difficulties encountered in the actual preparation of the specimen. The second group includes those effects which result in the destruction of the supporting membrane of the specimen during observation. The third group includes the difficulties being encountered due to the effects of the electron beam on the specimen itself.

In the preparation of a specimen for the electron microscope, one of the first difficulties encountered is that due to the presence of impurities. The instrument is capable of detecting such minute quantities of materials, that impurities which exist in concentrations of only one part in several million can easily be detected. In the case of specimens of approximately known characteristica, such impurities are not of any great importance since they may be easily recognized for what they are. On the other hand, if the investigation is to be carried out with materials of unknown properties, the impurities present must be either eliminated completely, or identified in order that they may be recognized in subsequent work.

It is, of course, essential that the mounting membranes be absolutely free of any structure due to impurities in the materials used or to faults in the forming process. The most important difficulty to be found in the preparation of specimens from a liquid dispersion, is due to the surface tension of the liquids used. This effect is particularly annoying if the surface tension is such that the liquid does not wet the collodion, for, in this case, the liquid, upon drying, will gather in droplets around the larger particles of the specimen. It is exceedingly difficult to get an even distribution of the specimen material under such conditions. The difficulty can often be overcome by using one of the other methods of preparation.

Other phenomena which must be kept in mind in connection with this type of specimen, particularly when an aqueous suspension is used, are those due to changes in pH. with drying, changes in concentration with resulting changes in osmotic effects, and fractionation due to size selection by the method of preparation.

One of the most common effects encountered in the observation of specimens which contain some larger particles or groups of particles is the rupture of the supporting membrane due to electrostatic forces. Owing to the fact that the supporting membrane is an excellent insulator any charges which appear on the surfaces of larger particles due to the absorption of beam electrons tend to build up until appreciable potentials are reached. Such particles will be repelled by neighboring particles with a force strong enough to rupture the supporting membrane. Successful micrographs can seldom be made of specimens that have been ruptured in this way because they seldom reach an equilibrium state which is independent of beam intensity.

A second effect that may cause a membrane to rupture is the heating of particles by the absorption of beam electrons to temperatures above the melting point of the material of which the film is made. As in the preceding case, this phenomenon occurs only in presence of large particles. A cure for both difficulties may be found by eliminating the larger particles from the specimen.

When it is necessary to obtain a micrograph of a specimen which consists mainly of larger particles, it is often possible to use a low intensity illuminating beam and photographic focusing.

The effect of the electron beam itself on the specimen may appear in the electron image in a number of ways. These include the effects which are due to heating of the specimen, decomposition due to heat and excitation from the electron beam, evaporation in the vacuum and under the excitation of the electron beam, and finally, the killing of living specimens.

Since these effects are varied and have as yet not been studied in detail no more can be done here than to mention them and call them to the attention of the research worker who may be interested in investigating some specimen in which one or more of these effects occur.

SERVICE PARTS LIST

RCA ELECTRON MICROSCOPE

TYPE EMB-1
TYPE EMB-2
TYPE EMB-3
TYPE EMB-4

MAIN ASSEMBLY

Stock No.	Description	Dwg. No.
46673	Adapter—Ionization gauge adapter	
45847	Aperture—Condenser	
45849	Aperture—Electron gun assembly aperture	
45850	Aperture—Objective pole piece aperture	
46041	Aquastat—For diffusion pump	
MI-12962	Set of Batteries (Dry)	
47213	"B" Battery—Burgess #a-30, 45 volts. Plug in Type #738	
47214	"B" Battery—Burgess #4156, 22½ volts, #763	
47215	"B" Battery—Burgess #5156, 22½ volts, #778	
45550	Bearing—Specimen chamber valve screw bearing	
44054	Bellows—Camera chamber air lock	
44058	Bellows—Camera chamber cam valve	
46746	Bellows—Casette movement shaft bellows with shaft end, spacer and collar	
46982	Bellows—Specimen movement screw and casette movement shaft bellows "only"	
44051	Bellows—Electron gun	
44052	Bellows—Electron gun support specimen chamber and condenser support	
44057	Bellows—Intermediate tube	
44053	Bellows—Manifold (long)	
45282	Bellows—Manifold (short)	
44055	Bellows—Main valve	
44059	Bellows—Specimen chamber cam valve	
44055	Bellows—Specimen chamber specimen control and air lock	
45844	Bellows—Picture width and viewing screen knob	
46671	Belt—Vacuum pump belt, type EMB-1-2-3 only	
45558	Cam—Photographic and specimen chamber cam assembly	
47108	Cap—Specimen holder	
47656	Coating—Fluorescent dry coating for screens (1 oz. bottle)	
46042	Fan—Ventilating fan	
44511	Filament—Electron gun filament assembly	
23563	Fuse—1/10 amp.	
47859	Gasket—Camera knob (cassette control)	613792-1
47860	Gasket — Window—inter. tube, elec. gun (outer gasket)	613792-2
47861	Gasket—Specimen movement hand screws (type EMB-1-2-3 only)	613792-3
47862	Gasket—Cam valve assem.—spec. and photo. chambers (bearing flange)	613792-4
47863	Gasket—Window — spec. chamber (outer gasket)	613792-5
47864	Gasket—Window — viewing (outer) (type EMB-1-2 only)	613792-6
47865	Gasket—Manifold to electron gun	613792-7
47866	Gasket—Electron gun (top)	613792-8
47867	Gasket—Manifold to: Specimen, viewing, int. tube chambers	613792-9
47868	Gasket—Manifold to main valve	613792-10
47869	Gasket—Cradle mechanism (bearing flange)	613792-11
47870	Gasket—Main valve (gland flange)	613792-12
47871	Gasket—Aux. air line—both ends	613792-13
47872	Gasket—Electron gun (bottom)	613792-14
47873	Gasket—Photographic chamber—main valve gear bracket flange	613792-15
47874	Gasket—Main valve (bottom)	613792-16
47875	Gasket—For condenser coil	613792-17
47876	Gasket—For proj. coil and bottom of objective coil	613792-18
47877	Gasket—For obj. coil to spec. chamber	613792-19
47878	Gasket—View. chamber to photo. chamber	613792-20
47879	Gasket—Cam valve seats,—valve mechanism in spec. and photo chambers (bleeder) (aux.)	613792-21
47880	Gasket—Cam valve seats—valve mechanism in spec. and photo chambers (inner) (aux.)	613792-22

Stock No.	Description	Dwg. No.
47881	Gasket—Cradle mechanism gate valve seat	613792-23
47753	Gasket—Door spec. chamb. (B) housing for int. screen, int. manifolds	613792-24
47882	Gasket—Main valve disc (valve seat)	613792-25
47883	Gasket—Window — viewing chamber (inner) (type EMB-1-2 only)	613792-26
47884	Gasket—Windows—Inter. tube —elec. gun (inner gasket)	613792-27
47885	Gasket—Photo chamber—main valve seat	613792-28
47886	Gasket—Door (photo chamber)	613792-29
47887	Gasket—Window—spec. chamber (inner gasket)	613792-30
47888	Gasket—Knob control (sylphon gasket), screen, mask, and int. tube. type EMB-3-4 only)	613792-31
47889	Gasket—Knob control conversion kit (type EMB-1-2 only)	613792-32
47890	Gasket—Oil diff. pump—cover plate	613792-33
47891	Gasket—Wax box (cushion for resistor)	613792-34
47892	Gasket—Window — viewing chamber (type EMB 3-4 only)	613792-35
47893	Gasket—Spec. chamber—stage control (type EMB 4 only)	613792-44
47894	Gasket—Cushion — dampener for stage hold down springs (type EMB 4 only)	613792-45
46601	Gauge—Ionization gauge	
46600	Gauge—Thermocouple gauge (type EMB-1-2-3 only)	
47744	Gauge—Thermocouple gauge (type EMB-4 only)	
48030	Grease—Lubriko M-1 (tube)	
46352	Head—Knob sylphon head	
45561	Heater—Diffusion pump heater unit	
46604	Holder—Specimen holder	
45552	Insulator—Cathode rod insulator (lower)	
45553	Insulator—Cathode rod insulator (upper)	
45555	Knob—Picture width and viewing screen control knob	
46670	Motor—Vacuum pump motor (type EMB-1-2-3 only)	
45924	Oil—Diffusion pump oil (115 C. C. bottle)	
45562	Plate—Bearing plate for casette movement—shaft end	
46672	Pulley—Motor pulley (type EMB-1-2-3 only)	
46354	Ring—Knob sylphon thrust ring	
47628	Screen—Specimen screen (approx. 500 in box)	
45560	Screen—Viewing screen	
45846	Screw—Filament set screw (#2-56 slotted head)	
46703	Screw—Filament set screw (#4-40 Allen head)	
45556	Screw—Knob holding screw	
45557	Screw—Knob thread engaging screw	
45549	Screw—Specimen chamber valve screw—less bearing and knob	
45548	Screw—Specimen moving scew assembly	
46353	Seat—Knob sylphon seat for screen control and picture width knob	
45551	Shield—Electron gun glass shield	
45546	Spring—Movable stage spring	
45542	Spring—Cam valve inner spring	
45543	Spring—Cam valve middle spring	
45544	Spring—Cam valve outer spring	
45545	Spring—Specimen holder raising mechanism spring	
44218	Tongs—Pole piece tongs	
44523	Valve—Glass vacuum valve	
46698	Wax—Picein wax	
45845	Window—Electron gun assembly and intermediate tube window	
45848	Window—Specimen chamber window	
45554	Window—Viewing chamber window	
44521	Wrench—Spanner wrench for windows, etc.	
46699	Wrench—Allen head wrench—#4 screw	
19996	Wrench—Allen head wrench—#6 screw	
14991	Wrench—Allen head wrench—#8 screw	
26581	Wrench—Allen head wrench—#10 and #12 screw	
22112	Wrench—Allen head wrench—¼" screw	
22113	Wrench—Allen head wrench—5/16" screw	
22111	Wrench—Allen head wrench—⅜" screw	
46605	Film making kit	
MI-12977	Casette and cover	
MI-7443	Touch-up enamel kit	
47968	Tubing—Vacuum pump—10 ft. length	
MI-12976	Stereoscopic specimen holder	

ELECTRON MICROSCOPE
CONTROL PANEL

Symbol No.	Description	Stock No.
A1	Pilot lamp assembly — With green disc lamp only	23216
A2	Pilot lamp assembly — With red disc lamp only	23216
A3	Lamp—Neon lamp — clear — medium screw base—1 watt, 110 volts	47688
A4	Pilot lamp assembly — With amber disc lamp only	23216
C50	Capacitor—.01 mfd.	14393
C52	Capacitor—1.0 mfd.	18416
C53	Capacitor—.01 mfd.	14393
F1	Fuse—Cartridge fuse—2 amperes	3883
F2, F3	Fuse—Plug fuse—20 amperes	
M1	Meter—Thermocouple gauge (I input)	46027
M2	Meter—Thermocouple gauge (E output)	46028
M3	Meter—Ionization gauge (input)	46029
M4	Meter—Ionization gauge (output)	46030
M5	Meter—Beam current	46031
M6	Meter—Test meter	46032
R1	Resistor—1000 ohms, 10 watt	64557
R9	Resistor—10 ohms	43989
R18	Resistor—39,000 ohms, 1 watt	30434
R19	Resistor—15,000 ohms, 1 watt	5114
R20	Resistor—4700 ohms, 1 watt	30788
R21	Resistor—56,000 ohms, 1 watt	17440
R22	Resistor—22,000 ohms, 2 watt	19081
R23	Resistor—100,000 ohms, 1 watt	3058
R24	Resistor—1000 ohms, 10 watt	64557
R57	Resistor—215 ohms, 15 watt	43992
R63	Control—3500 ohms, 50 watt	44000
R64	Resistor—750 ohms, 50 watt	64555
R67	Control—1000 ohms, 4 watt	18366
R68	Resistor—3900 ohms, 1 watt	31960
R70	Resistor—1000 ohms, 2 watt	44049
R71	Resistor—7500 ohms, ½ watt	44047
R72	Resistor—75,000 ohms, ½ watt	35256
R73	Resistor—750,000 ohms, ½ watt	44048
R76	Control—20 ohms, 4 watt	19105
R77	Resistor—750 ohms, 10 watt	46074
R78	Control—1000 ohms, 50 watt	43861
R85	Resistor—970 ohms	44010
R86	Resistor—750 ohms	44002
R87	Resistor—590 ohms	44003
R88	Resistor—480 ohms	44011
R89	Resistor—380 ohms	44012
R90	Resistor—307 ohms	44013
R91	Resistor—233 ohms	44014
R92	Resistor—195 ohms, 4 watt	44015
R93	Resistor—154 ohms, 4 watt	44016
R94	Resistor—626 ohms, 15 watt	44017
R96 to 115 inclusive	Resistor—10,000 ohms, 50 watt	46075
R116	Resistor—20,000 ohms	44018
R117	Control—25,000 ohms, 9 watt	44001
R118	Resistor—100,000 ohms, 1 watt	3058
R157	Resistor—10 ohms	43989
R158	Control—8000 ohms, 50 watt	44223
R159	Resistor—1 megohm	44019
R160	Resistor—5.5 ohms	44020
R161	Resistor—6 ohms	44021
R162	Resistor—6.5 ohms	44022
R163	Resistor—7.2 ohms	44023
R164	Resistor—8 ohms	44033
R165	Resistor—9 ohms	44024
R166	Resistor—10 ohms	44025
R167	Resistor—10.9 ohms	44026
R168	Resistor—11.9 ohms	44027
R169	Resistor—13 ohms	44028
R170	Resistor—16.7 ohms	44029
R171	Resistor—19 ohms	44030
R172	Resistor—23 ohms	44031
R173	Resistor—27.5 ohms	44032
R174	Resistor—36 ohms	44004
R175	Resistor—49 ohms	44005
R176	Resistor—72 ohms	44006
R177	Resistor—112 ohms	44007
R178	Resistor—217 ohms	44008
R179	Resistor—1316 ohms	44009
R180	Resistor—60,000 ohms, 20 watt	46067
R183	Resistor—1000 ohms, 10 watt	64557
S1	Switch—D.P.S.T. vac. ind. power	17602
S2	Switch—D.P.S.T. main power	
S3	Switch—S.P.S.T. control panel illumination	
S4	Switch—D.P.S.T. high voltage	17602
S6, S7	Switch—S.P.S.T. (S6 gun filament) (S7- ion. gauge filament)	
S8	Switch—Relay release	44034
S9	Relay—Overload	47477
S10	Switch—S.P.S.T. — projector lens	
S11	Switch — 21 contact projector lens control	46066
S12	Switch—S.P.S.T. condenser lens	
S13	Switch—6 contact—ionization gauge—range	
S14	Switch—11 contact, high voltage—range	45902
S15	Switch—2 contact test switch	18786
S16	Switch—21 contact obj. lens fine	46066
S17	Switch—11 contact, obj. lens coarse	46073
S18	Switch—S.P.S.T. obj. lens	
	Base—For panel illum. lamp (2 reqd.)	45944

Symbol No.	Description	Stock No.	Symbol No.	Description	Stock No.
	Cap—End cap for panel illum. lamp (2 reqd.)	45945		Lamp—Panel illuminating lamp	46403
	Holder—Cartridge fuse	32059		Socket—8 contact tube socket	31319
	Holder—Plug fuse and neon lamp	23540		Knob—Control knob—large	17268
				Knob—Control knob—small	30075

CHASSIS ASSEMBLY

Symbol No.	Description	Stock No.	Symbol No.	Description	Stock No.
C1, C2, C3	Capacitor—1 mfd., 1500 volts	43993	L15	Coil—Choke coil tapped	64556
C4	Capacitor—.05 mfd., 800 volts	44040	L16	Choke—Filter choke	46044
C5	Capacitor—1 mfd., 1000 volts	43994	L17	Choke—Filter choke	46045
C6	Capacitor—560 mmfd.	39646	L18, L19	Choke—Filter choke	46044
C7	Capacitor—.1 mfd., 1200 volts	44041	L20	Choke—Filter choke	46046
C8, C9	Capacitor—.5 mfd., 200 volts	30860	L21	Reactor	26440
C10	Capacitor—.5 mfd., 1000 volts	43995	L22, L23, L24, L25	Choke—Filter choke	46044
C15	Capacitor—.25 mfd. 500 volts	30849			
C17	Capacitor—.1 mfd., 1200 volts	44041	L26	Choke—Filter choke	46046
C18	Capacitor—.5 mfd., 1000 volts	43995	R2	Resistor—560 ohms, ½ watt	5164
C19, C20	Capacitor—.5 mfd., 200 volts	30860	R3	Resistor—560,000 ohms, 1 watt	32726
C21	Capacitor—1000 mmfd.	12635	R4	Resistor—5000 ohms, 10 watt	46051
C22, C23	Capacitor—.05 mfd., 1600 volts	44042	R5	Resistor—50,000 ohms, 20 watt	46065
C24, C25, C26, C27	Capacitor—125 mfd.	18434	R6	Resistor—1 megohm, 1 watt	2546
			R7	Resistor—50,000 ohms, 50 watt	46063
C28, C29, C30	Capacitor—3-3-6 mfd., 600 volts	43996	R8	Resistor—1 megohm, 1 watt	2546
C31	Capacitor—.1 mfd., 500 volts	30848	R10	Resistor—20,000 ohms, 25 watt	46060
C32	Capacitor—1 mfd., 400 volts	44043	R11	Resistor—5000 ohms, 10 watt	64554
C33, C34, C35, C36	Capacitor—125 mfd.	18434	R12	Resistor—100 ohms, 25 watt	46058
			R15	Resistor—20,000 ohms, 10 watt	46052
C37	Capacitor—.1 mfd., 500 volts	30848	R16	Resistor—100,000 ohms, 1 watt	3058
C38	Capacitor—2¾ mfd., 600 volts	43997	R17	Resistor—82,000 ohms, 1 watt	30435
C39	Capacitor—125 mfd.	18434	R25	Resistor—560 ohms, ½ watt	5164
C40	Capacitor—.5 mfd., 200 volts	30860	R26	Resistor—100,000 ohms, 50 watt	46069
C41, C42, C43, C44	Capacitor—125 mfd.	18434	R27	Resistor—220,000 ohms, ½ watt	14583
C45	Capacitor—.1 mfd., 500 volts	30848	R28	Resistor—10,000 ohms, 10 watt	46053
C46	Capacitor—2 mfd., 600 volts	43998	R29	Resistor—680,000 ohms, ½ watt	30562
C47	Capacitor—90 mfd., 400 volts	33023			
C48	Capacitor—.25 mfd., 500 volts	30849	R30	Resistor—560,000 ohms, ½ watt	30653
C49	Capacitor—125 mfd.	18434			
C51	Capacitor—.1 mfd., 500 volts	30848	R31	Resistor—560 ohms, ½ watt	5164
C54	Capacitor—330 mmfd.	12952	R32	Resistor—2200 ohms, ½ watt	34767
C55	Capacitor—1 mfd., 150 volts	18416	R33	Resistor—560 ohms, ½ watt	5164
C56	Capacitor—1 mfd., 400 volts	44043	R34	Resistor—2200 ohms, ½ watt	34767
C57	Capacitor—.15 mfd.	44044	R35	Resistor—560 ohms, ½ watt	5164
C58, C59	Capacitor—1 mfd., 600 volts	44045	R36	Resistor—2200 ohms, ½ watt	34767
C60	Capacitor—.003 mfd. (3 required)	NF-3002	R37	Resistor—560 ohms, ½ watt	5164
			R38	Resistor—2200 ohms, ½ watt	34767
C61	Capacitor—.01 mfd.	14393	R39	Resistor—100,000 ohms, 50 watt	46069
C62	Capacitor—.025 mfd., 1000 volts	30859			
C63	Capacitor—22 mmfd.	14021	R40	Resistor—15,000 ohms, 10 watt	46054
C64	Capacitor—1 mfd., 250 volts	11897	R41	Resistor—220,000 ohms, ½ watt	14583
C65	Capacitor—1 mfd., 600 volts	44045			
C66	Capacitor—.0015 mfd.	13762	R42	Resistor—1000 ohms, 25 watt	46055
C67	Capacitor—.1 mfd., 500 volts	30848	R43	Resistor—270 ohms, ½ watt	30929
C68	Capacitor—Order as per markings on defective part.		R44	Resistor—560,000 ohms, ½ watt	30653
L1, L2, L12	Reactor—80 m. h.	46050	R45	Resistor—100,000 ohms, 20 watt	28577
L13	Coil—Output plate	44221			

Symbol No.	Description	Stock No.
R46	Resistor—10,000 ohms, 10 watt	46053
R47	Resistor—300 ohms, 25 watt	46061
R48	Resistor—5 ohms	43990
R50, R51	Resistor—560 ohms, ½ watt	5164
R52	Resistor—2200 ohms, ½ watt	34767
R53	Resistor—560,000 ohms, ½ watt	30653
R54	Resistor—470,000 ohms, ½ watt	30648
R55	Resistor—3.9 megohm, 1 watt	44046
R56	Resistor—220,000 ohms, ½ watt	14583
R58	Resistor—5 ohms	43990
R59	Resistor—560 ohms, ½ watt	5164
R60	Resistor—560,000 ohms, ½ watt	30653
R61	Resistor—100,000 ohms, 20 watt	28577
R62	Resistor—25,000 ohms, 10 watt	28414
R65	Resistor—5 ohms	43990
R66	Resistor—3000 ohms, 50 watt	46064
R69	Resistor—100,000 ohms, ½ watt	3252
R75	Resistor—5000 ohms, 10 watt	46051
R79	Resistor—350 ohms, 10 watt	46056
R80	Resistor—820,000 ohms, ½ watt	30161
R81, R82	Resistor—560 ohms, ½ watt	5164
R83	Resistor—2200 ohms, ½ watt	34767
R84	Resistor—100,000 ohms, ½ watt	3252
R95	Resistor—5 ohms	43990
R120	Resistor—560,000 ohms, ½ watt	30653
R121	Resistor—20,000 ohms, 10 watt	46052
R122	Resistor—60,000 ohms, 20 watt	46067
R123	Resistor—390,000 ohms, 1 watt	32725
R124	Resistor—1 megohm, 1 watt	2546
R125	Resistor—8200 ohms, ½ watt	30650
R126, R127	Resistor—5600 ohms, ½ watt	30734
R128	Resistor—2200 ohms, 1 watt	13486
R129	Resistor—2.2 megohm, ½ watt	30649
R130	Resistor—30,000 ohms, 20 watt	46068
R131	Resistor—500 ohms, 10 watt	46077
R132	Resistor—1000 ohms, ½ watt	34766
R133	Resistor—10,000 ohms, 32 watt	46076
R134	Resistor—2 ohms	43991
R135	Resistor—20 ohms, 10 watt	46057
R136	Resistor—10 ohms, ½ watt	31071
R137, R138	Resistor—560 ohms, ½ watt	5164
R139	Resistor—1000 ohms, 1 watt	30152
R140	Resistor—10 ohms, ½ watt	31071
R141, R142	Resistor—560 ohms, ½ watt	5164
R143	Resistor—10 ohms, ½ watt	31071
R144, R145	Resistor—560 ohms, ½ watt	5164
R146	Resistor—10 ohms, ½ watt	31071
R147, R148	Resistor—560 ohms, ½ watt	5164
R149	Resistor—4700 ohms, 2 watt	46043
R150	Resistor—15,000 ohms, 10 watt	46054
R151	Resistor—500 ohms, 10 watt	46077
R152	Resistor—5600 ohms, 1 watt	11298
R153	Resistor—10,000 ohms, ½ watt	3078
R154	Resistor—750 ohms, 50 watt	46062
R155	Resistor—7500 ohms, 25 watt	46059
R156	Resistor—10 ohms	43989
R181	Resistor—6000 ohms, 25 watt	46072
R182	Resistor—4000 ohms, 50 watt	46071
RX2	Rectifier—Bolt type	46070
T2	Transformer—R-f feed back	44219
T3	Transformer—(T-19P58)	46047
T4	Transformer—(T-19F90)	46048
T5	Transformer—(T-19F99)	46033
T6	Transformer—(T-19F98)	46034
T7	Transformer—(T-19F93)	46035
T8	Transformer—(T-19F99)	46033
T9	Transformer—(T-15R01)	46036
T10	Transformer—(T-70R61)	46037
T11	Transformer—(T-15R01)	46036
T12	Transformer—T-67R97	46038
T13	Transformer—T-69R35	46039
T14	Transformer—T-70R62	46040
T15	Transformer—T-67R97	46038
T16	Transformer—T-19F98	46034
T17	Transformer—T-50F61	46049
	Connector—3 contact chassis female connector	26411
	Connector—Chassis female connector	19569
	Receptacle—Fan receptacle	33792
	Socket—4 contact tube socket	19448
	Socket—5 contact tube socket	46702
	Socket—7 contact tube socket	46701
	Socket—8 contact tube socket	31319

OIL TANK

Symbol No.	Description	Stock No.
C11	Capacitor—.003 mfd.	UC-3046
C12	Capacitor—.0002 mfd.	44037
C14	Capacitor—.005 mfd., 75,000 volts	44036
C16	Capacitor—.006 mfd.	UC-3021
L3, L4	Coil—Rectifier filament primary	426224-501
L5, L6, L7, L8, L9	Coil—F.F. drive	858751-501
L10	Coil—Rectifier filament secondary	858752-501
L11	Coil—Ripple resonating coil	426226-501
R13	Resistor—200,000 ohms	44038
R14	Resistor—1000 megohms, 100,000 volts	44039
R49	Resistor—100 ohms	503073-60
T1	Transformer	718377-501
V52, V53	Tube—Rectifier	46602
	60 kilovolt divider complete	47243

ELECTRON MICROSCOPE - TYPE B

VACUUM TUBE DATA - ALL VOLTAGES MEASURED TO GND.
SCHEMATIC - W-302790

EQUIPMENT - MI-12955, 12955A, 12955B, 12955C
A.C. SUPPLY 118 VOLTS, 60 CYCLES, 17 AMP.

TUBE NO.	TUBE TYPE	FUNCTION	OPER. CONDITION	E PLATE	E SCREEN	E CATH.	E GRID	E HEATER	E FILTER	I PLATE	I SCREEN	I CATH.	I HEATER	PLATE RESISTOR OHMS	PLATE RESISTOR WATTS	SCREEN RESISTOR OHMS	SCREEN RESISTOR WATTS	CATHODE RESISTOR OHMS	CATHODE RESISTOR WATTS	PLATE WATTS	SCREEN WATTS	TUBE NO.
1	1616	RECTIFIER	NORMAL	1400RC	—	1350	—	2.5	—	.078	—	.078	5.0	—	—	—	—	—	—	97.5	—	1
2	1616	"	"	1400RC	—	1350	—	2.5	—	.078	—	.078	5.0	—	—	—	—	—	—	97.5	—	2
3	5U4G	"	"	650AC	—	560	—	5.0	—	.175	—	.175	3.0	—	—	—	—	—	—	98	—	3
4	5U4G	"	"	650AC	—	560	—	5.0	—	.175	—	.175	3.0	—	—	—	—	—	—	98	—	4
5	5V4G	"	"	325AC	—	123	—	5.0	—	.035	—	.035	2.0	—	—	—	—	—	—	4.4	—	5
6	5U4G	"	"	575AC	—	620	—	5.0	—	.167	—	.167	3.0	—	—	—	—	—	—	103	—	6
7	5U4G	"	"	575AC	—	650	—	5.0	—	.167	—	.167	3.0	—	—	—	—	—	—	103	—	7
8	5V4G	"	"	180AC	—	185	—	5.0	—	.150	—	.140	2.0	—	—	—	—	—	—	21.5	—	8
9	5U4G	"	"	430AC	—	400	—	5.0	—	.104	—	.104	3.0	—	—	—	—	—	—	41.6	—	9
10	5R4G	"	"	300AC	—	300	—	5.0	—	.120	—	.120	3.0	—	—	—	—	—	—	36.0	—	10
11	5Y3G	"	"	180AC	—	184	—	5.0	—	.070	—	.030	2.0	—	—	—	—	—	—	12.9	—	11
12	811	SERIES REGULATOR	"	1250	—	905	940	6.3	—	.150	—	.150	4.0	—	—	—	—	—	—	51.8	—	12
13	6L6G	DC AMPLIFIER	"	1250	1250	940	895	6.3	—	.006	.001	.007	.9	—	—	560	—	5000	.25	1.86	.31	13
14	802	" "	"	895	100	0	-14	6.3	12.50	.00068	.00015	.00078	.9	560000	1W	—	—	—	—	.56	.015	14
15	812	OSCILLATOR	"	900	—	0	-185	6.3	—	.070	—	.085	4.0	—	—	—	—	—	—	63	—	15
16	812	" "	"	400	—	0	-18	6.3	—	.040	—	.043	4.0	—	—	—	—	—	—	16	—	16
17	6V6	" "	"	165	170	17	-9	6.3	400	.025	.006	.034	.45	—	—	—	—	500	5W	3.7	1.22	17
18	6L6	POWER AMP.	"	560	185	0	-120	6.3	—	.075	.006	.083	.9	—	—	—	—	—	—	42	1.47	18
19	6L6	" "	"	560	185	0	-120	6.3	—	.075	.006	.083	.9	—	—	—	—	—	—	42	1.47	19
20	6L6	" "	"	560	185	0	-120	6.3	—	.075	.006	.083	.9	—	—	—	—	—	—	42	1.47	20
21	6L6	" "	"	560	185	0	-120	6.3	—	.075	.006	.083	.9	—	—	—	—	—	—	42	1.47	21
22	6Y6G	DC AMP.	"	210	100	0	-15	6.3	—	.048	.0015	.0495	1.25	3000	6W	5600	.005	—	—	10	.15	22
23	6Y6G	" "	"	210	100	0	-15	6.3	—	.048	.0015	.0495	1.25	SEE TUBE # 22		5600	.005	—	—	10	.15	23
24	VR105	VOLT. REG.	"	105	—	0	—	—	560	.042		.042	—	10000	20W	—	—	—	—	4.4	—	24
25	12SJ7	DC AMP.	"	145	100	0	-5.5	12.6	—	.0005	.0001	.0006	.15	390000	.1W	60000	1.5	—	—	.072	.01	25
26	6Y6G	SERIES REG.	"	123	123	0	-18	6.3	—	.024	.002	.026	1.25	—	—	560	.062	—	—	4.2	.25	26
27	VR105	VOLT. REG.	"	255	—	150	—	—	—	.010	—	.010	—	—	—	—	—	—	—	1.53	—	27
28	VR150	" "	"	150	—	0	—	—	—	.010	—	.010	—	—	—	—	—	—	—	1.50	—	28
29	6SF5	D.C. AMP.	"	-18	—	-180	-180.5	6.3	—	.00051	—	.00051	.30	4800000	.2W	—	—	10000	1.0	.05	—	29
30	6Y6G	SERIES REG.	"	185	185	68	41	6.3	—	.023	.002	.025	1.25	—	—	270	.001	—	—	2.0	.25	30
31	6SF5	DC. AMP.	"	41	—	0	-.5	6.3	—	.00069	—	.00069	.30	560000	.2W	—	—	—	—	.028	—	31
32	6Y6G	SIGNAL REG	"	450	450	410	380	6.3	—	.044	.003	.047	1.25	—	—	540		—	—	19.8	.75	32
33	6Y6G	" "	"	450	450	410	380	6.3	—	.044	.003	.047	1.25	—	—	540		—	—	19.8	.75	33
34	6Y6G	" "	"	450	450	410	380	6.3	—	.044	.003	.047	1.25	—	—	540		—	—	19.8	.75	34
35	6Y6G	" "	"	450	450	410	380	6.3	—	.044	.003	.047	1.25	—	—	540		—	—	19.8	.75	35

MI-12955C

ELECTRON MICROSCOPE - TYPE B

VACUUM TUBE DATA - ALL VOLTAGES MEASURED TO G.N.D.
SCHEMATIC W-302790

EQUIPMENT MI-12955, 12955A, 12955B, 12965-C
A.C. SUPPLY 118 VOLTS, 60 CYCLES, 17 AMP.

TUBE NO.	TUBE TYPE	FUNCTION	OPER. CONDITION	E PLATE	E SCREEN	E CATH.	E GRID	E HEATER	E FILTER	I PLATE	I SCREEN	I CATH.	I HEATER	PLATE RESISTOR OHMS	PLATE RESISTOR WATTS	SCREEN RESISTOR OHMS	SCREEN RESISTOR WATTS	CATHODE RESISTOR OHMS	CATHODE RESISTOR WATTS	PLATE WATTS	SCREEN WATTS	TUBE NO.
36	VR105	VOLT REG.	NORMAL	210	—	105	—	—	—	.015	—	.015	—	15000	2.2	—	—	—	—	3.15	—	36
37	VR105	" "	"	105	—	0	—	—	—	.015	—	.015	—	—	—	—	—	—	—	1.58	—	37
38	6SJ7	DC AMP.	"	380	215	105	190	6.3	—	.00048	.0001	.00058	.3	560000	.15	—	—	—	—	.1832	.011	38
39	GY60	SERIES REG.	MAX. CUR.	465	265	195	195	6.3	—	.114	.004	.120	1.25	—	—	560	.92	—	—	13.7	.72	39
40	GL60	" "	NORMAL	405	405	103	76	6.3	—	.050	.002	.052	.9	—	—	560	.002	—	—	19.8	.37	40
41	GL60	" "	"	405	400	103	76	6.3	—	.050	.002	.052	.9	—	—	560	.002	—	—	19.8	.37	41
42	GL60	" "	"	320	320	195	190	6.3	—	.028	.002	.030	.9	3500	.03	560	.002	—	—	9.0	.31	42
43	GL60	" "	"	320	320	195	190	6.3	—	.028	.002	.030	.9	3500	.03	560	.002	—	—	9.0	.31	43
44	5Y3	DC AMP.	"	170	—	8	1.0	2.5	—	.0032	—	.0032	1.0	3900	—	—	—	—	—	.49	—	44
45	6SFE	" "	MAX CUR.	135	—	0	-1.2	6.3	—	.00047	—	.00047	.3	—	—	—	—	—	—	.063	—	45
46	6SJ7	" "	NORMAL	135	29	0	-1.1	6.3	—	.00047	—	.00047	.3	280000	.13	—	—	—	—	.063	—	46
47	12SJ7	" "	"	190	65	0	-3.5	12.6	—	.00035	—	.00035	.17	800000	.053	—	—	—	—	.067	—	47
48	VR105	WATER PROTECTOR	"	—	—	—	—	—	—	0	—	0	—	—	—	—	—	—	—	—	—	48
49	VR105	RELAY "	"	—	—	—	—	—	—	0	—	0	—	—	—	—	—	—	—	—	—	49
50	C7B6	ION. GUAGE	"	1	—	25	*175	5.5	—	(VAR)*	—	.005		* TO 1000	.0001	—	—	5000	.125	—	—	50
51	C7B6	THER. "	"	—	—	—	—		—	—	—	—		—	—	—	—	—	—	—	—	51
52	6A3	RECTIFIER	"	30000	—	0	—	6.3	—	.0005	—	.0005		—	—	—	—	—	—	15	—	52
53	6B3	"	"	40000	—	30000	—	6.3	—	.0005	—	.0005		—	—	—	—	—	—	15	—	53

* VARIABLE

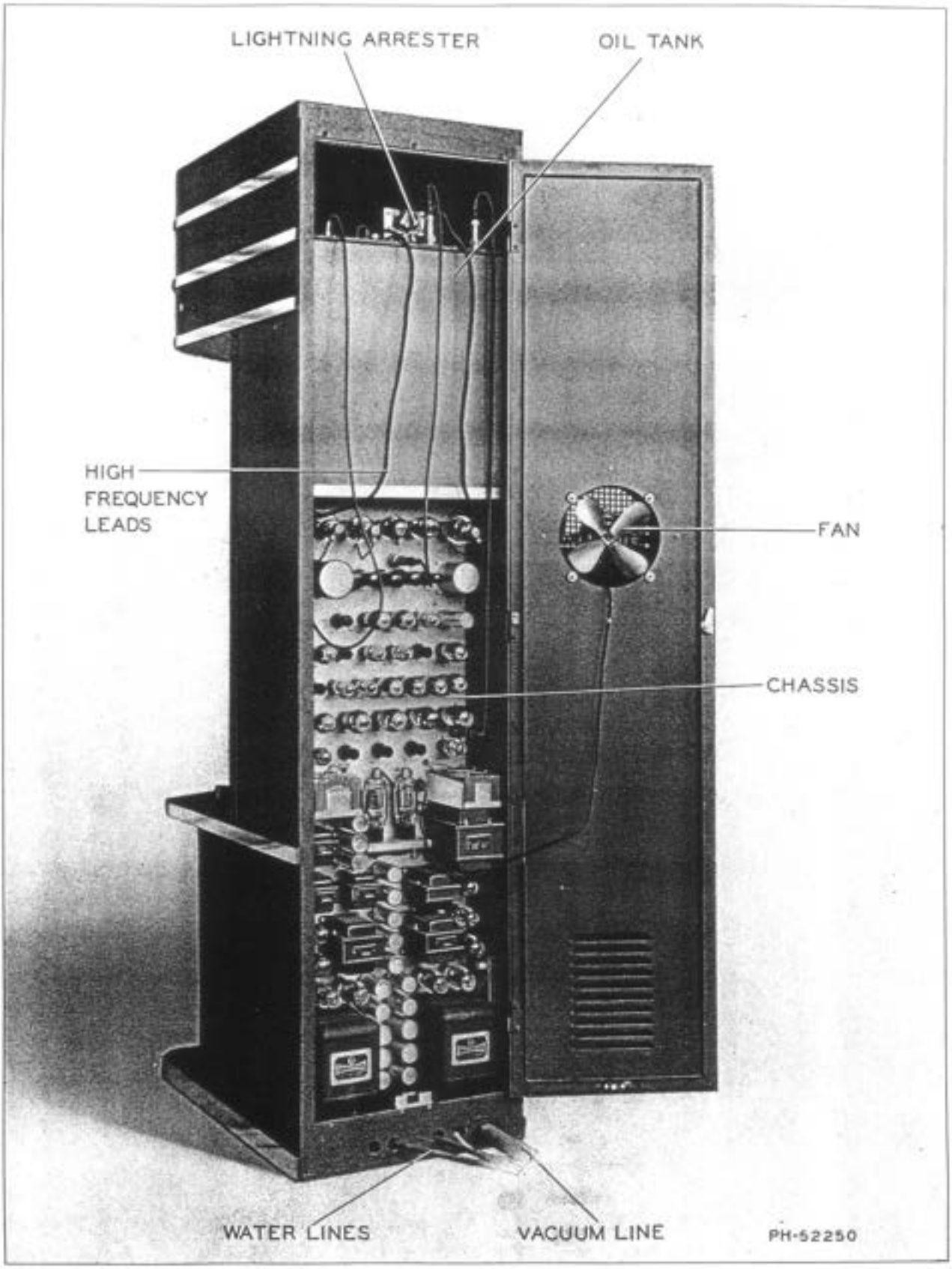

Figure 20—Electron Microscope, Rear View

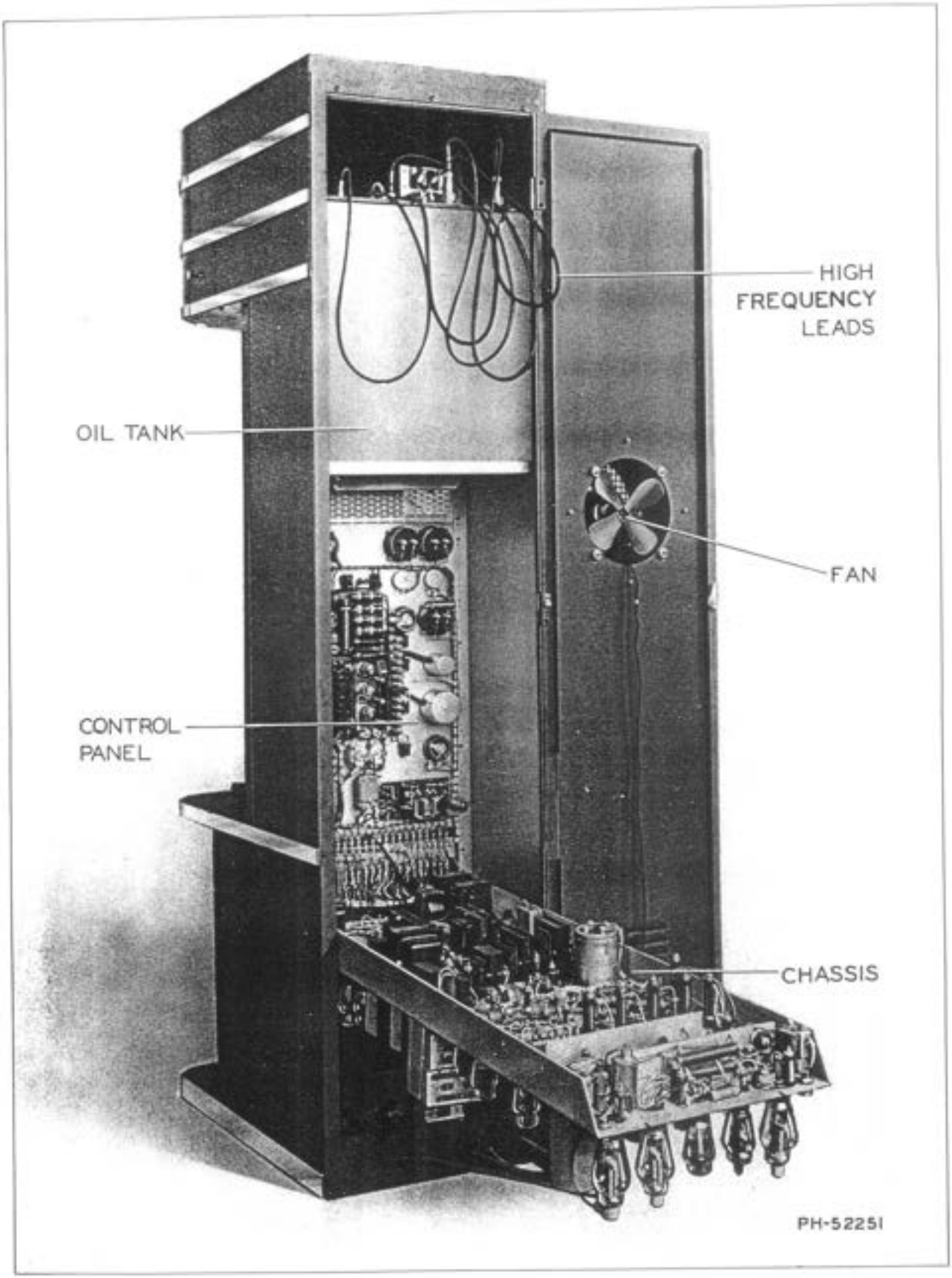

Figure 21—Electron Microscope, Rear View, Chassis Lowered

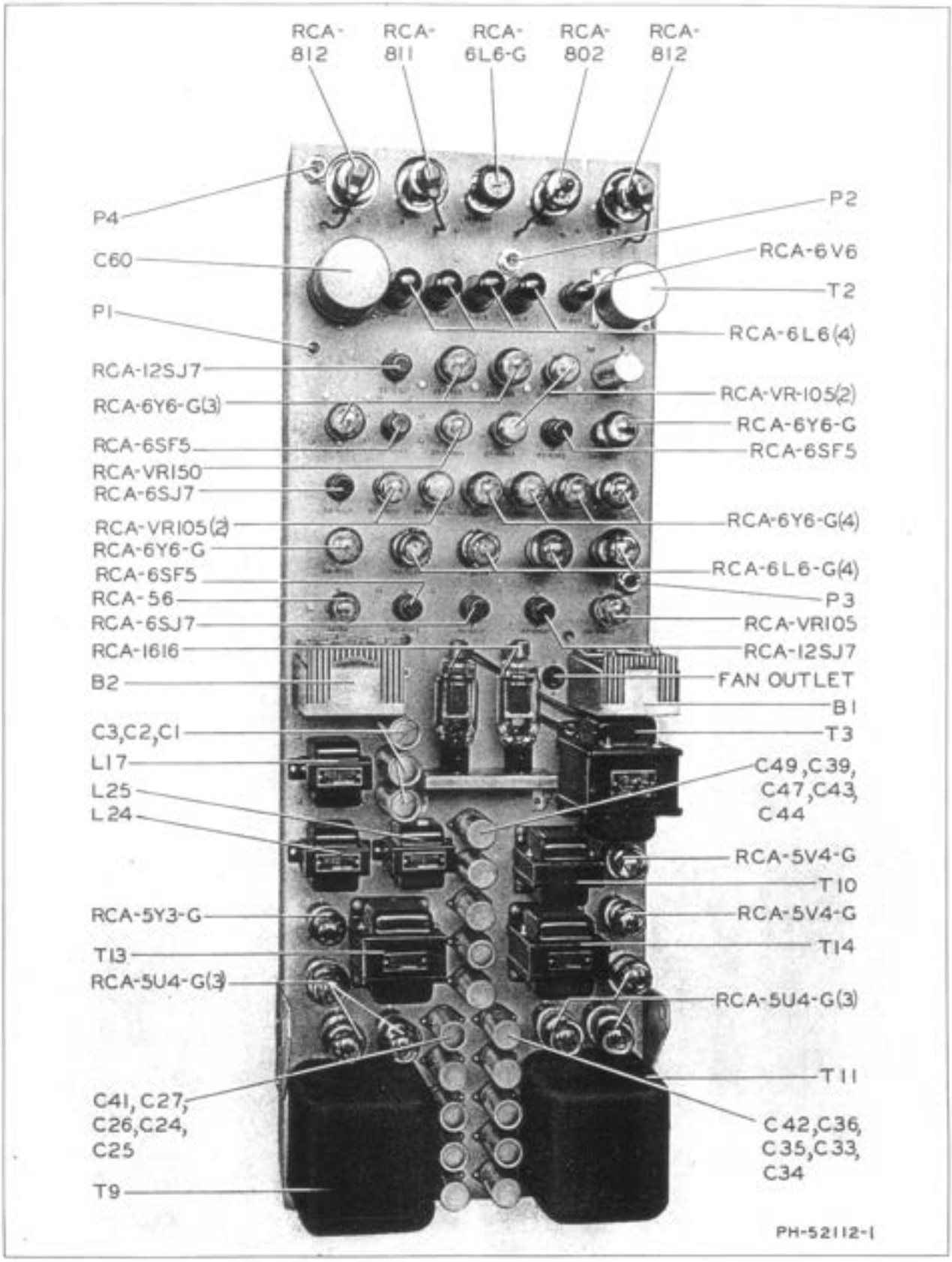

Figure 22—Electron Microscope, Chassis, Front View

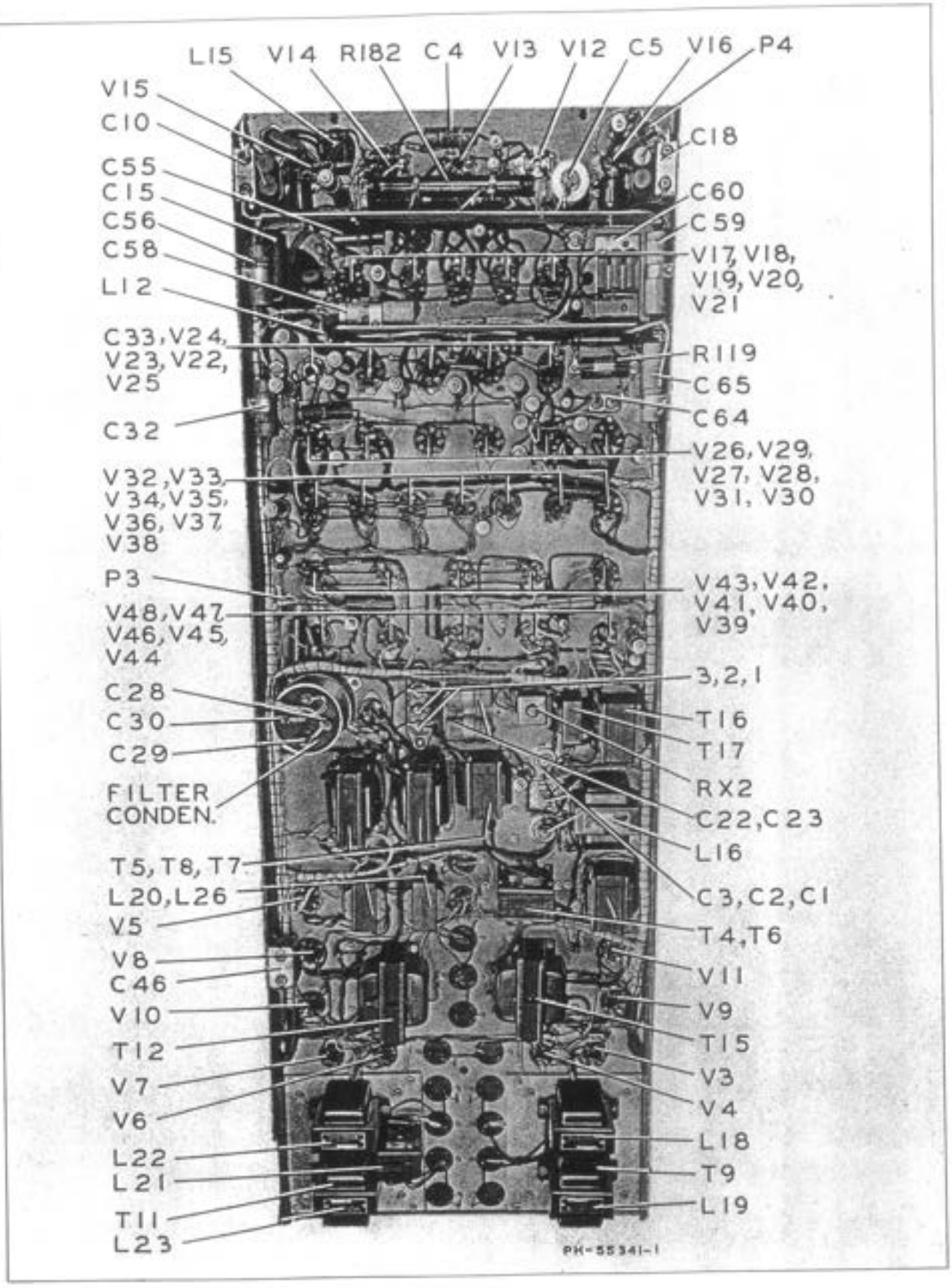

Figure 23—Electron Microscope, Chassis, Rear View

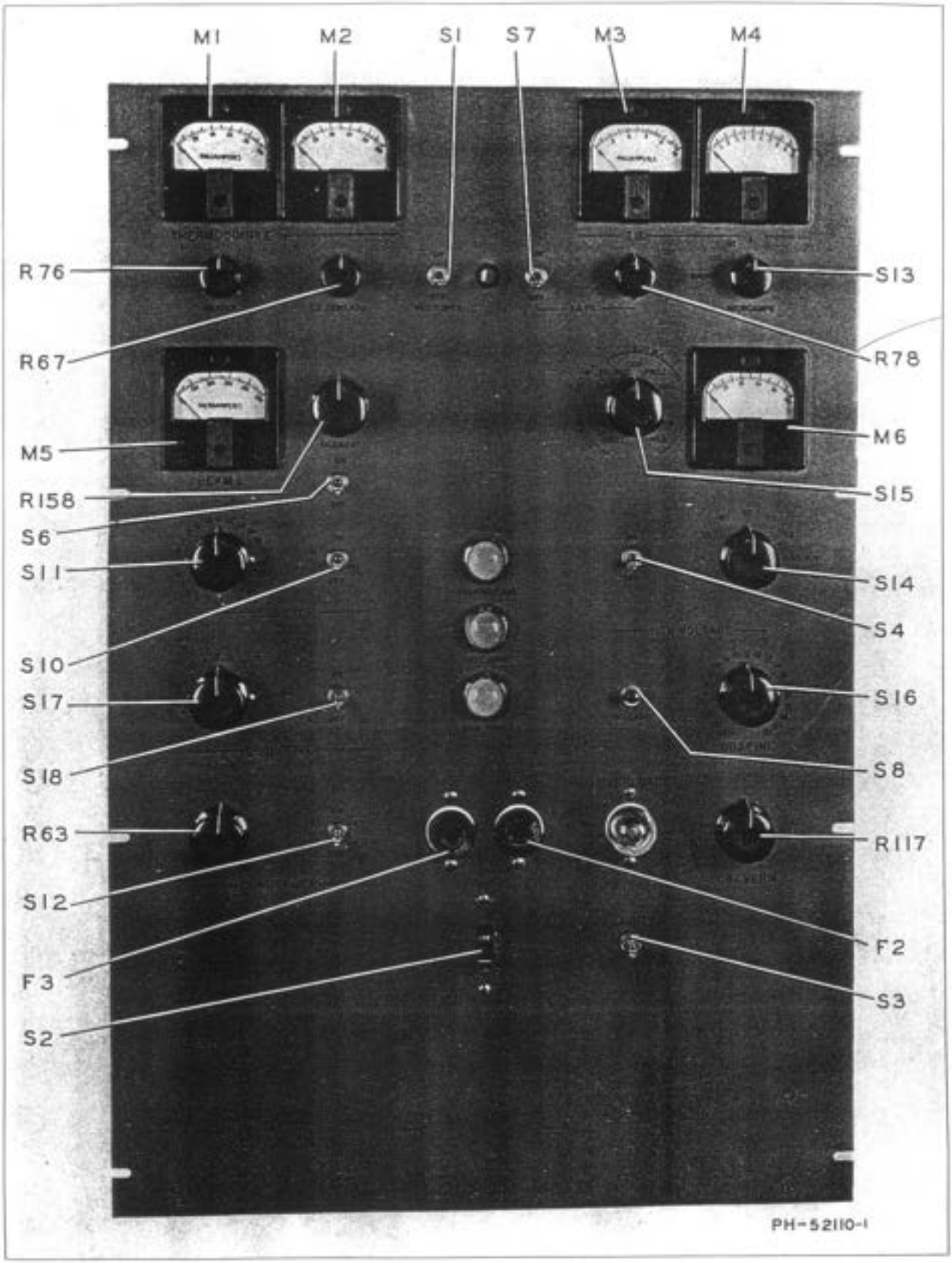

Figure 24—Control Panel, Front View

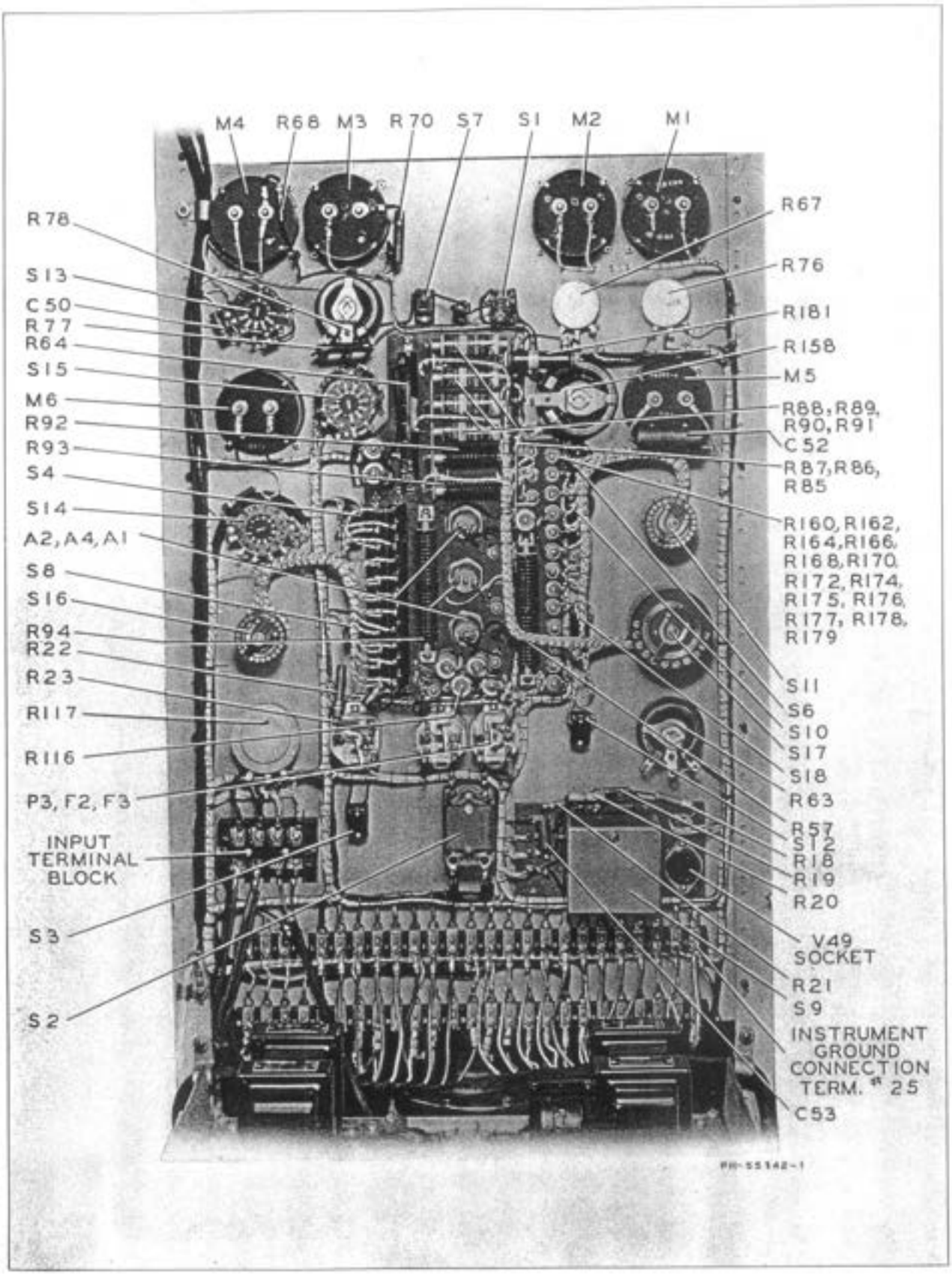

Figure 25—Control Panel, Rear View

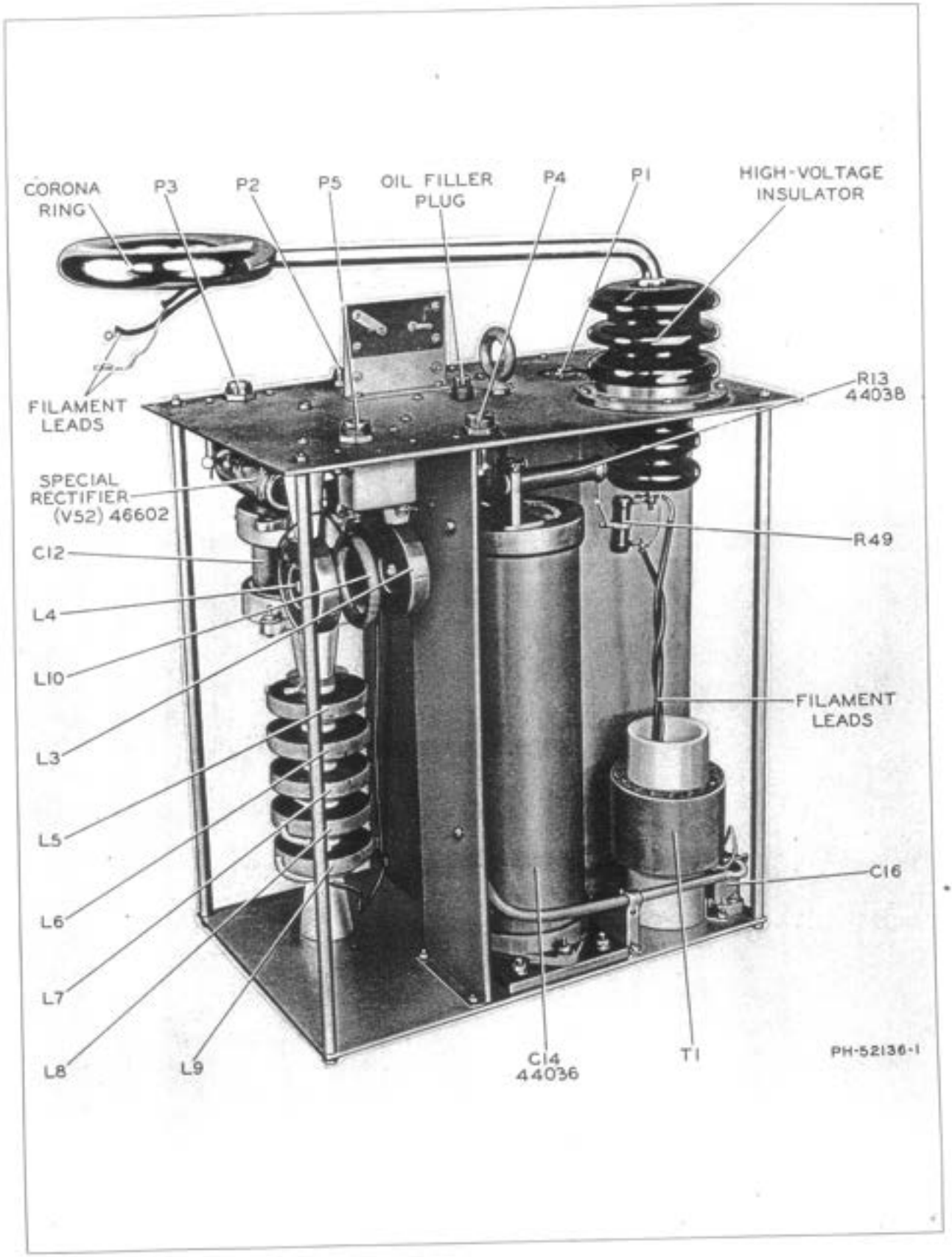

Figure 26—Oil Tank Assembly, Front View

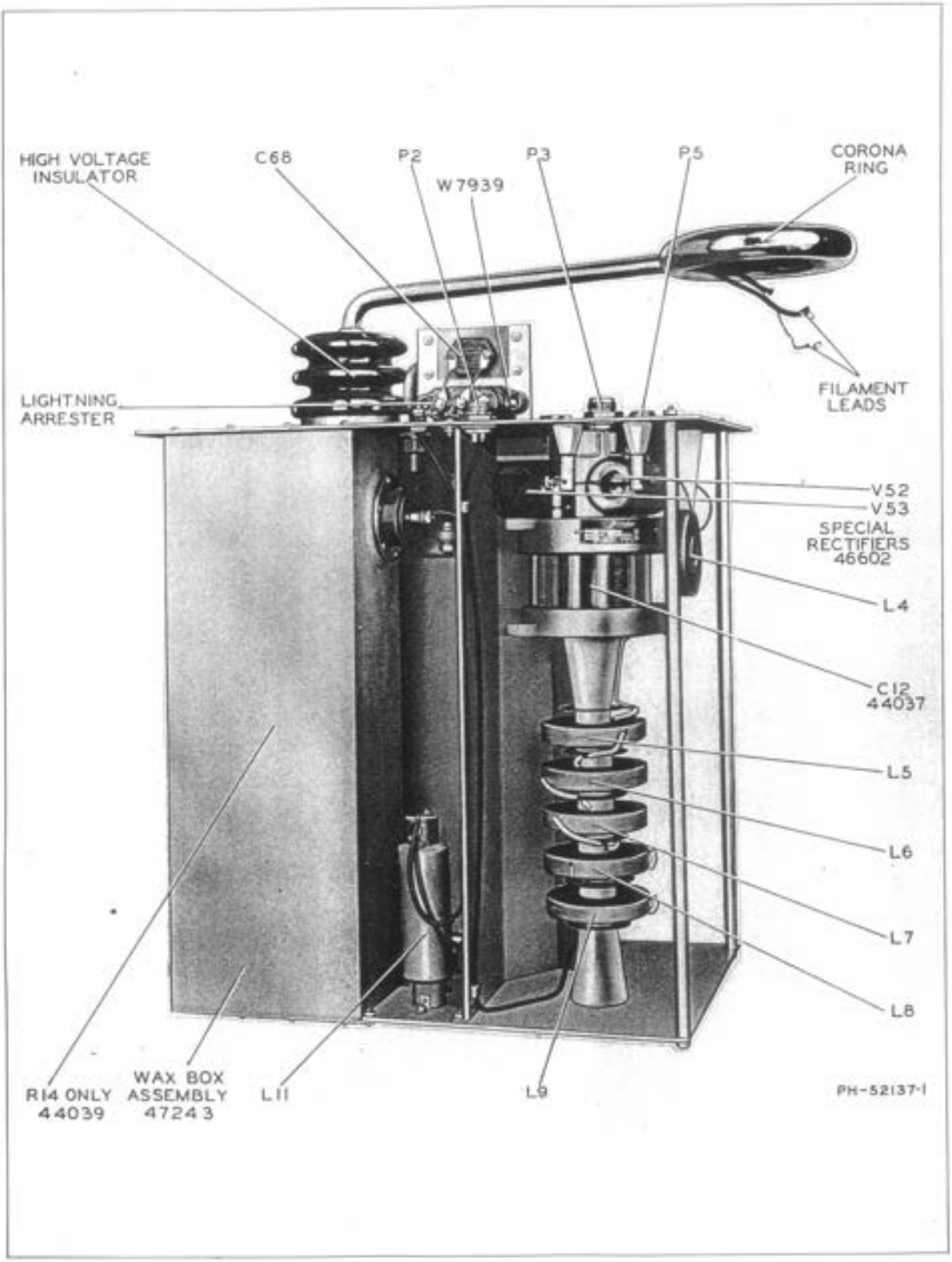

Figure 27—Oil Tank Assembly, Rear View

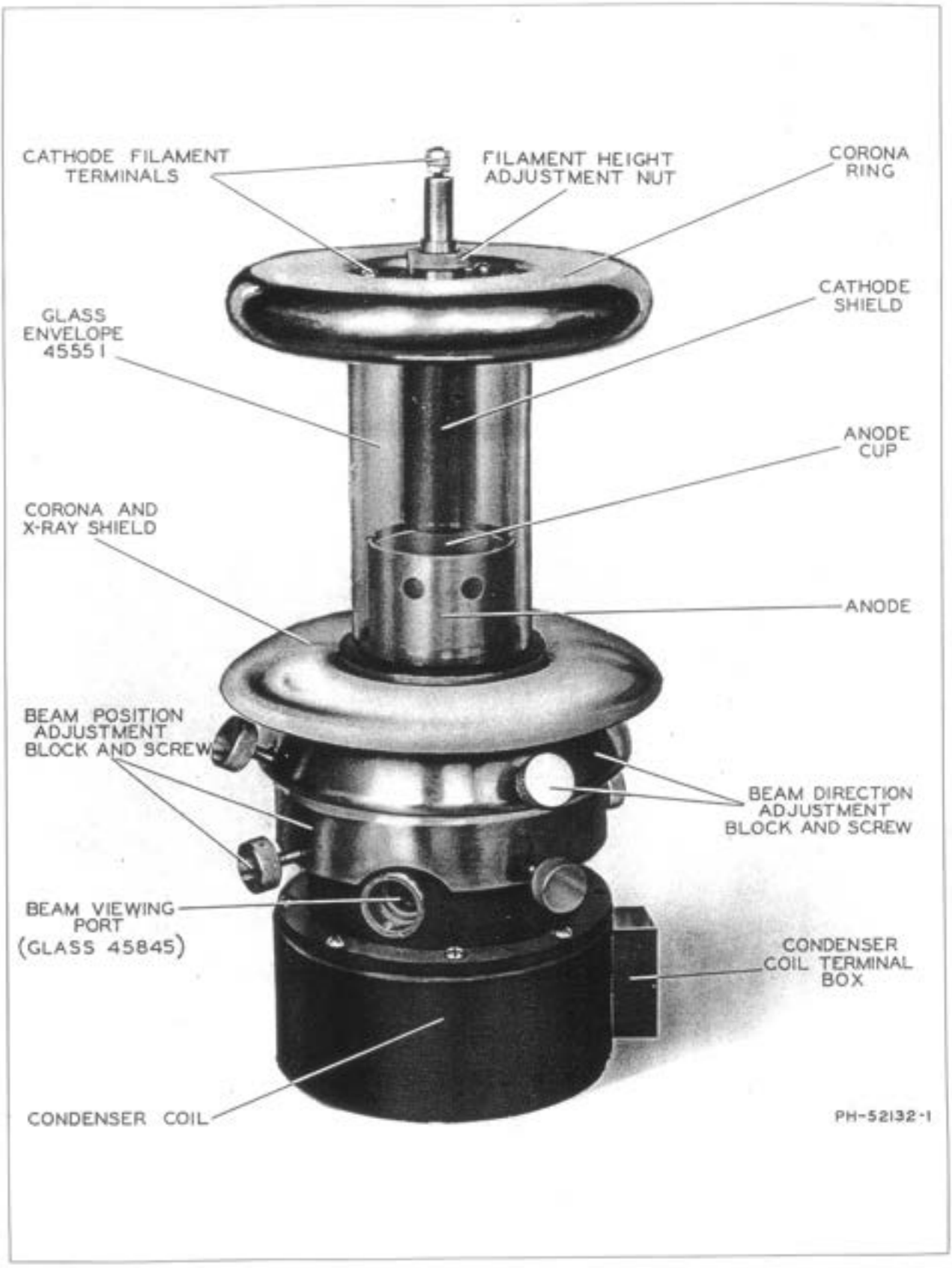

Figure 28—Electron Gun Assembly, Front View

Figure 29—Electron Gun Details

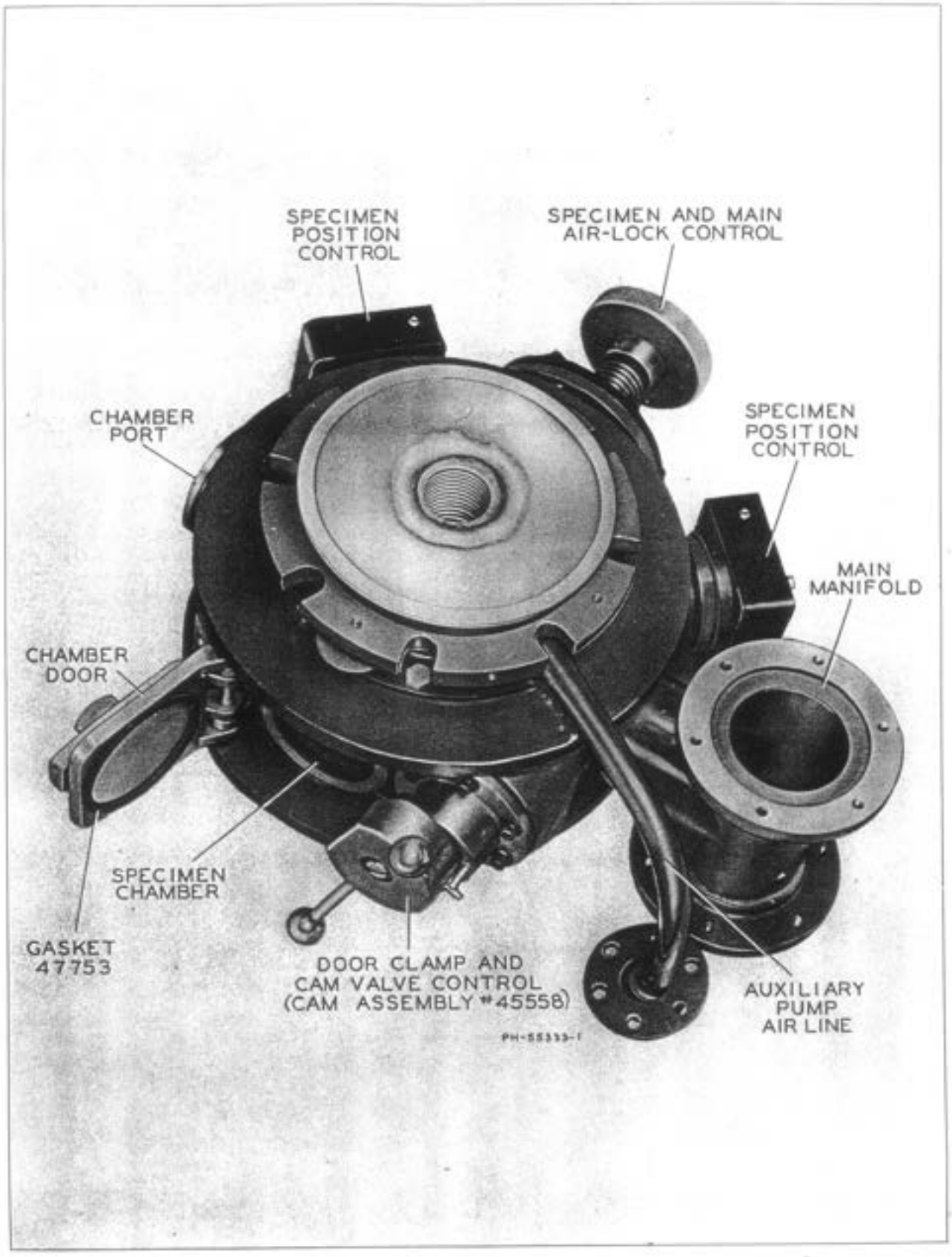

Figure 30—Specimen Chamber, Right Top View

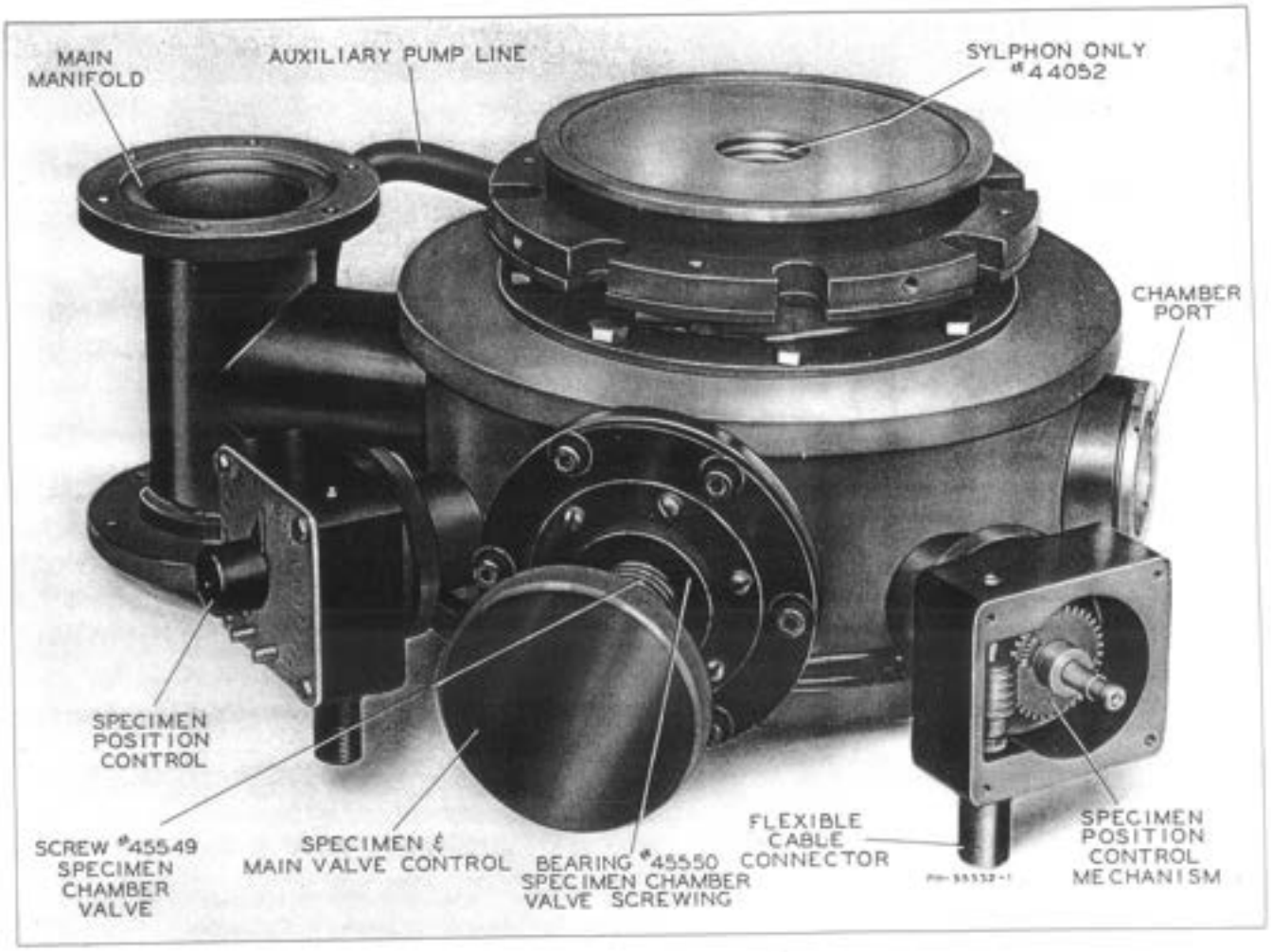

Figure 31—Specimen Chamber, Left Side View

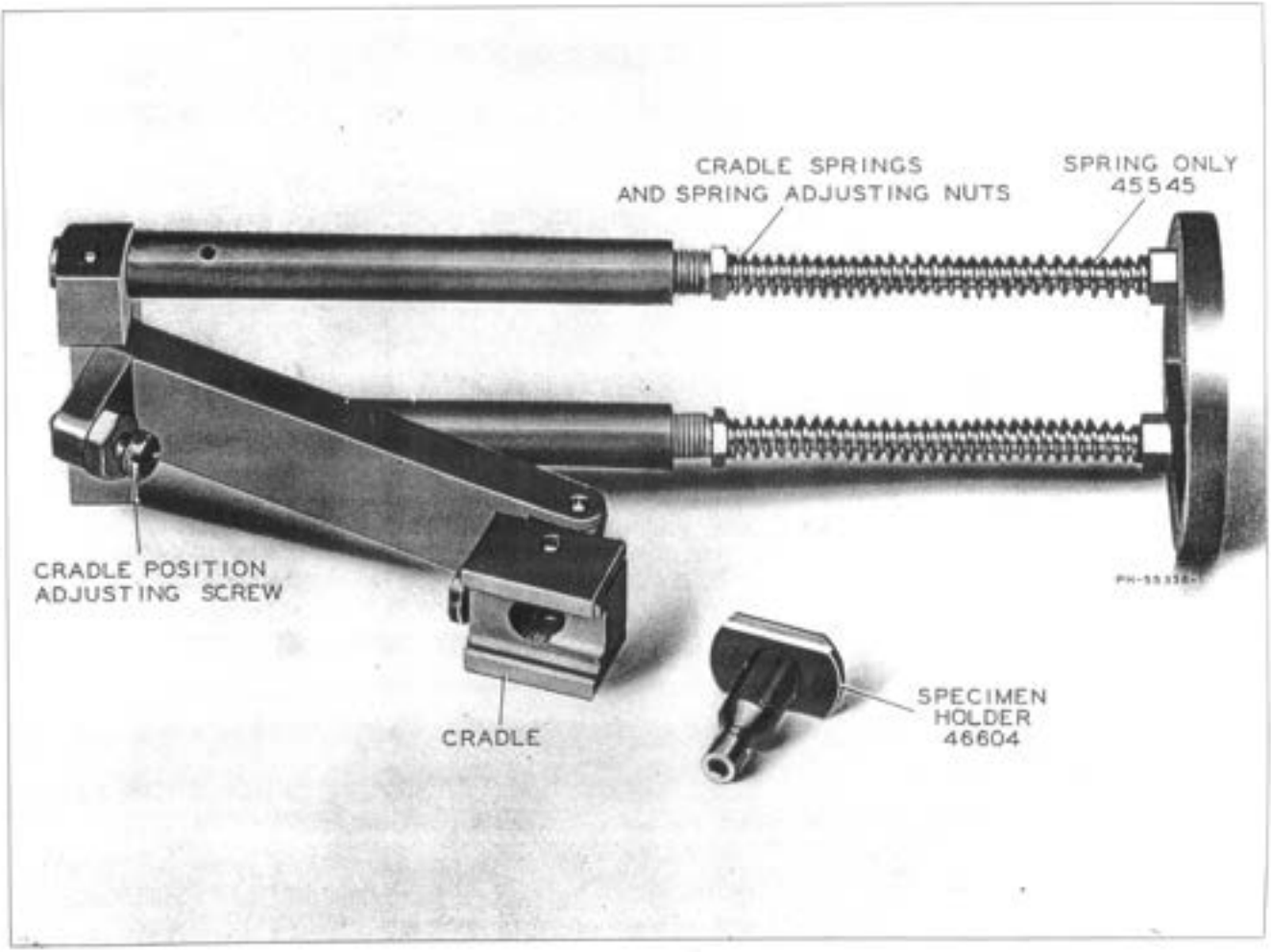

Figure 32—Specimen Holder and Cradle

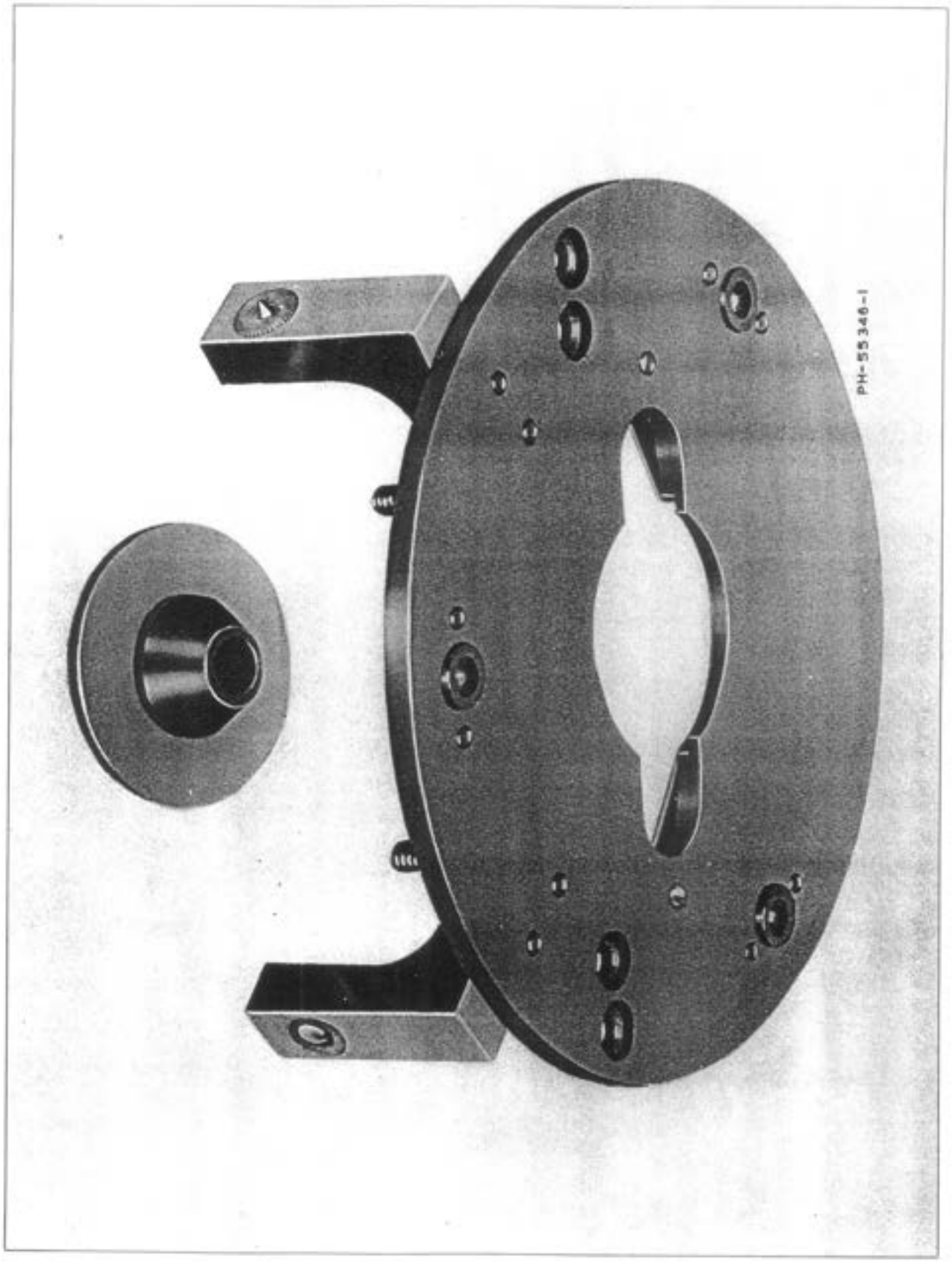

Figure 33—Specimen Chamber Stage Assembly

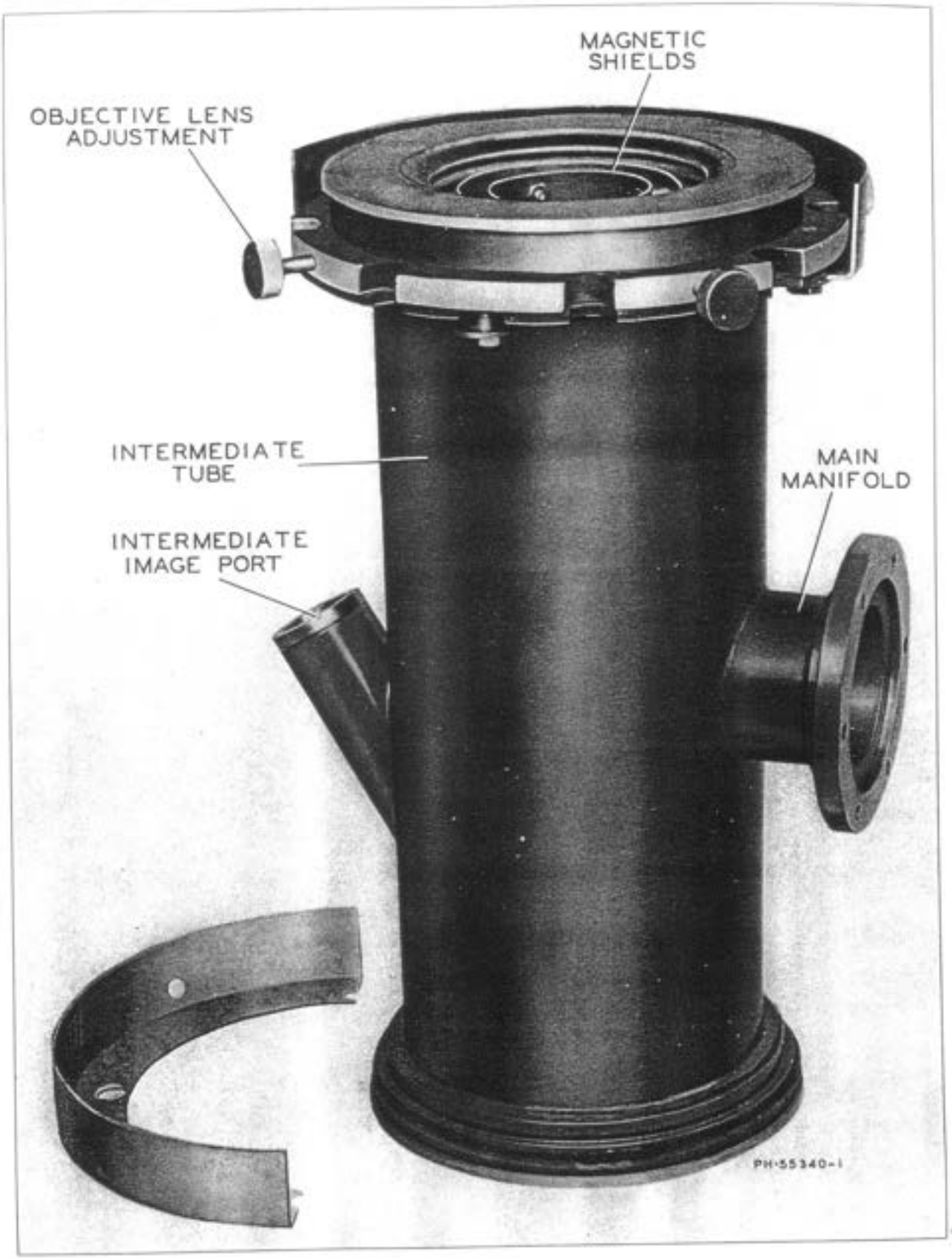

Figure 34—Intermediate Tube, Right Side View

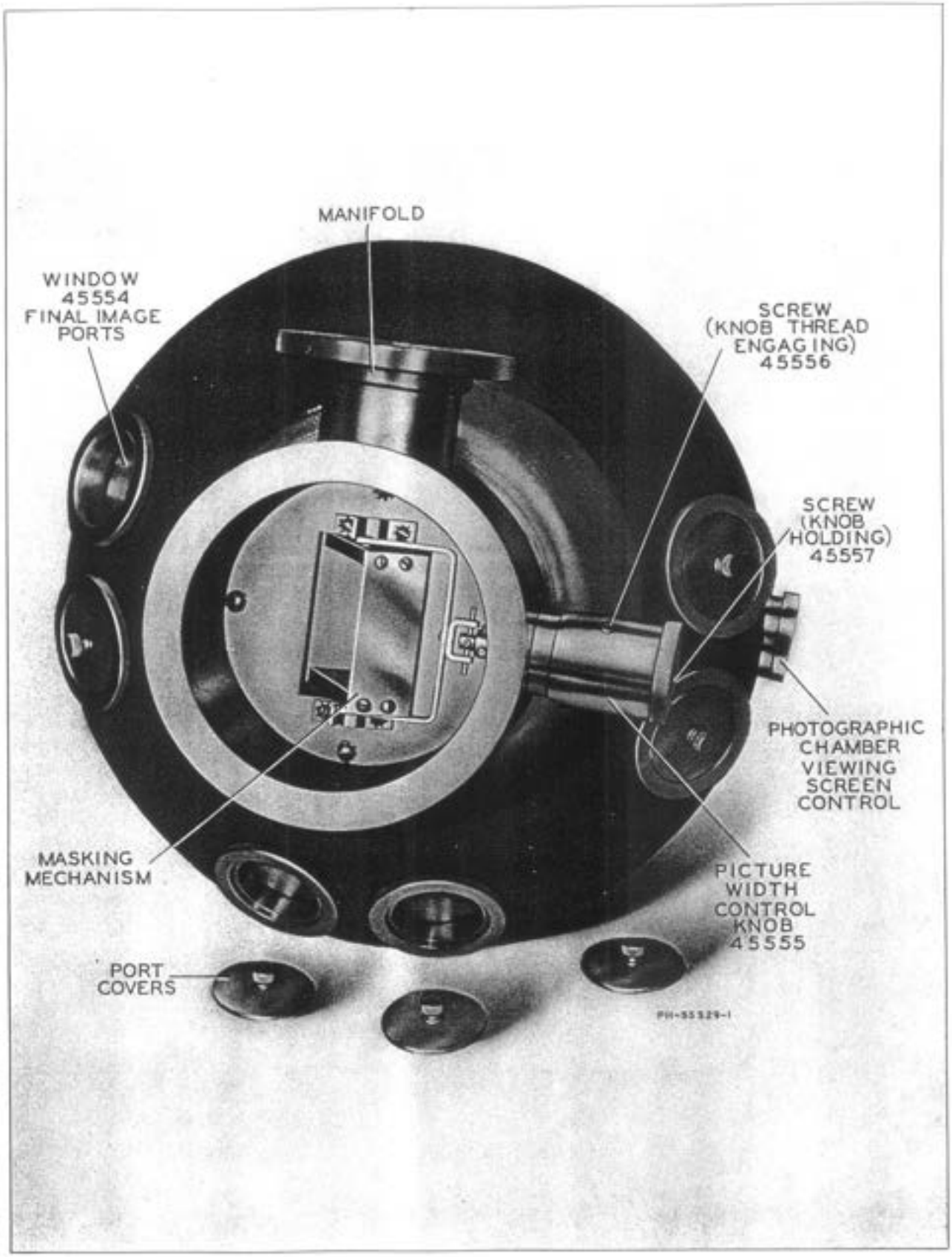

Figure 35—Lower Viewing Chamber, Top View

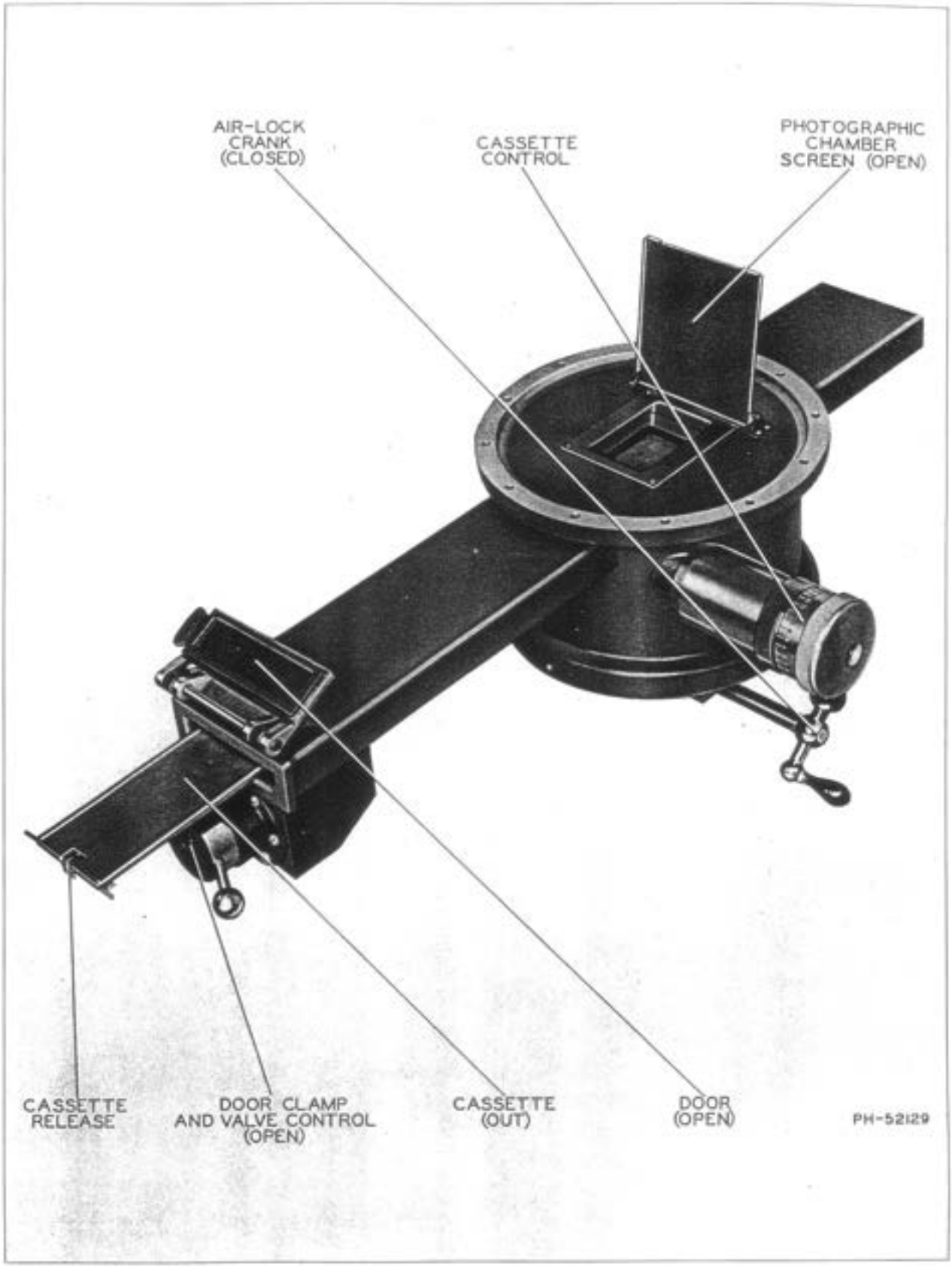

Figure 36—Photographic Chamber (Cassette Out)

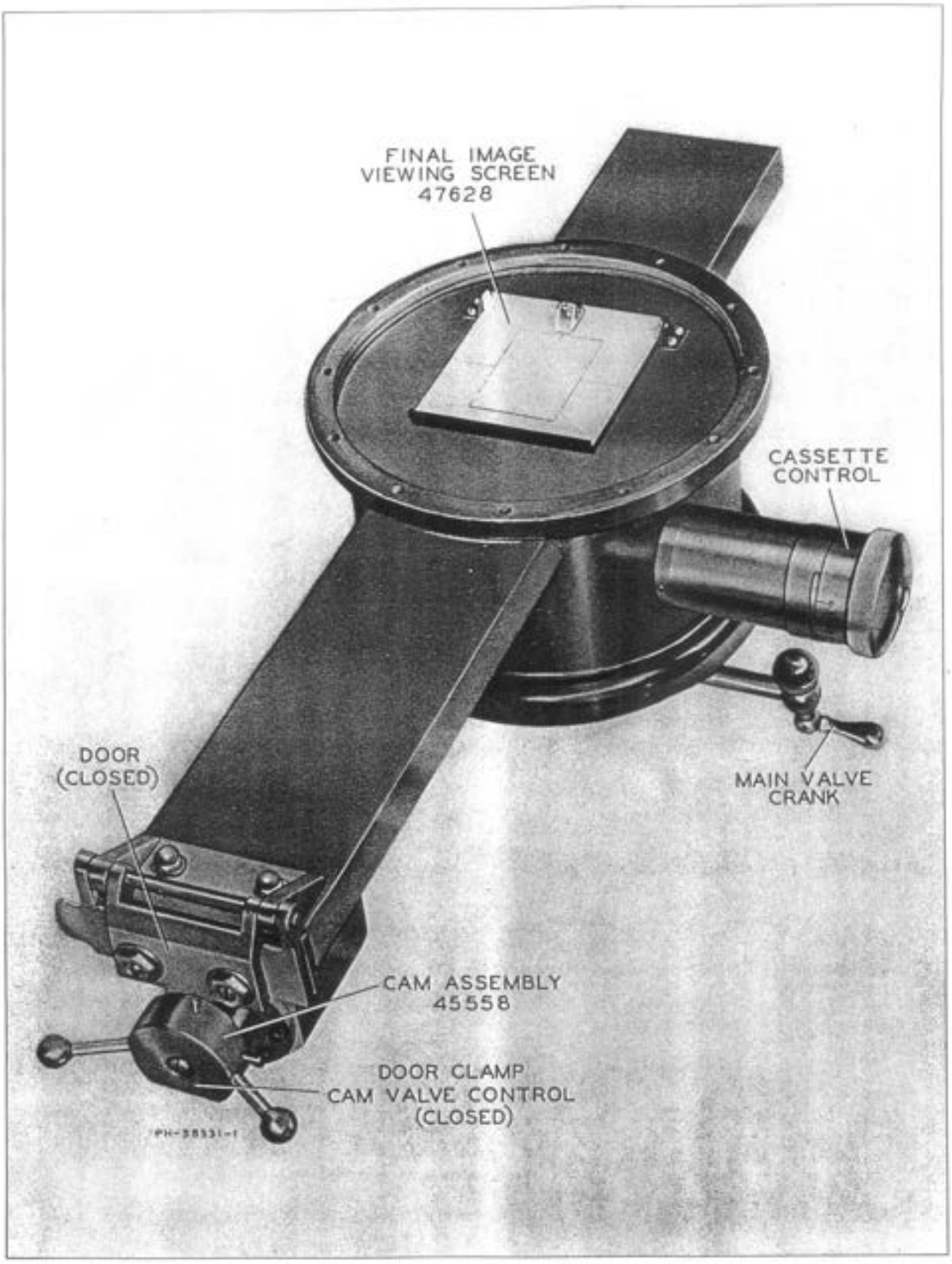

Figure 37—Photographic Chamber (Cassette In)

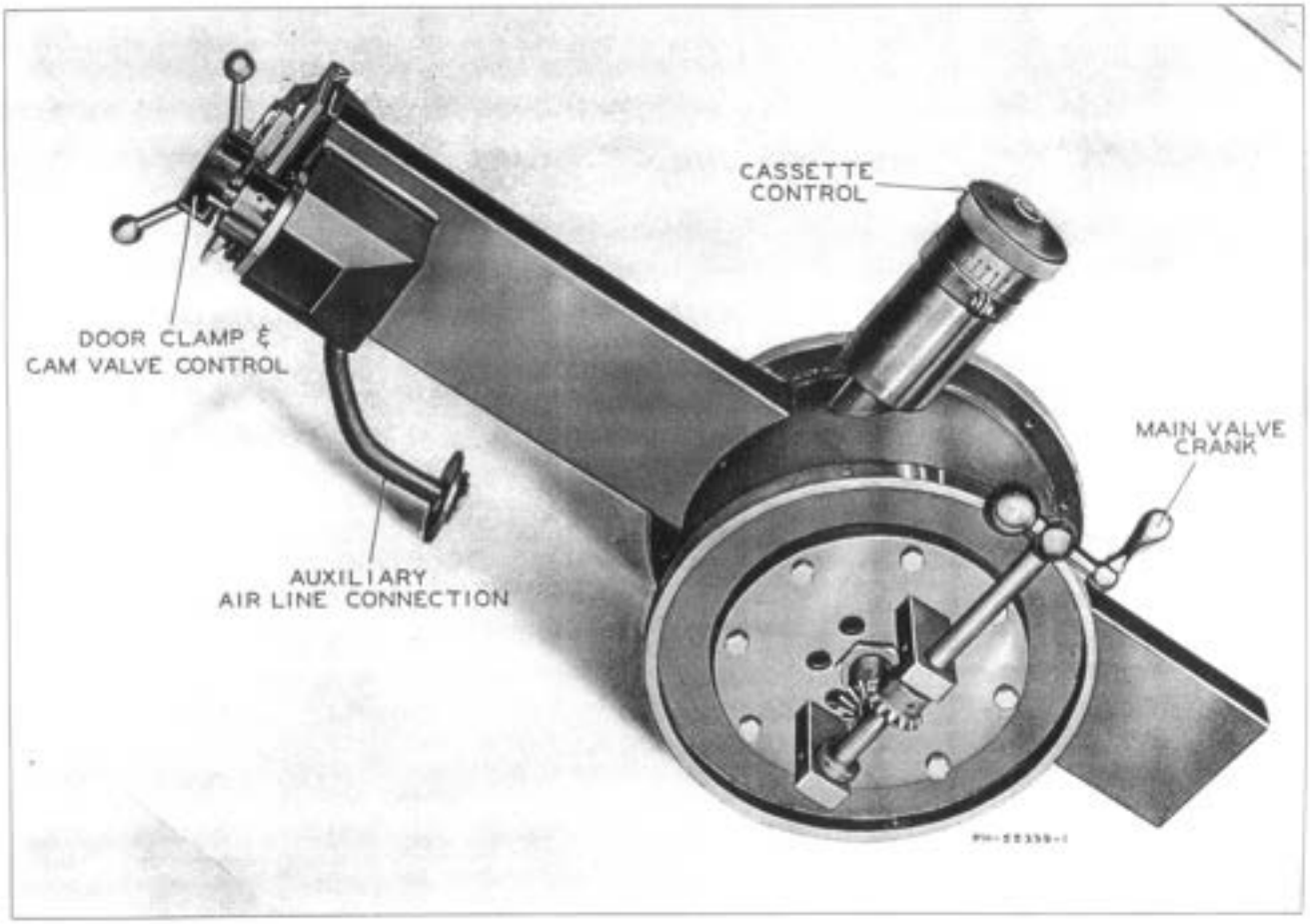

Figure 38.—Photographic Chamber, Bottom View

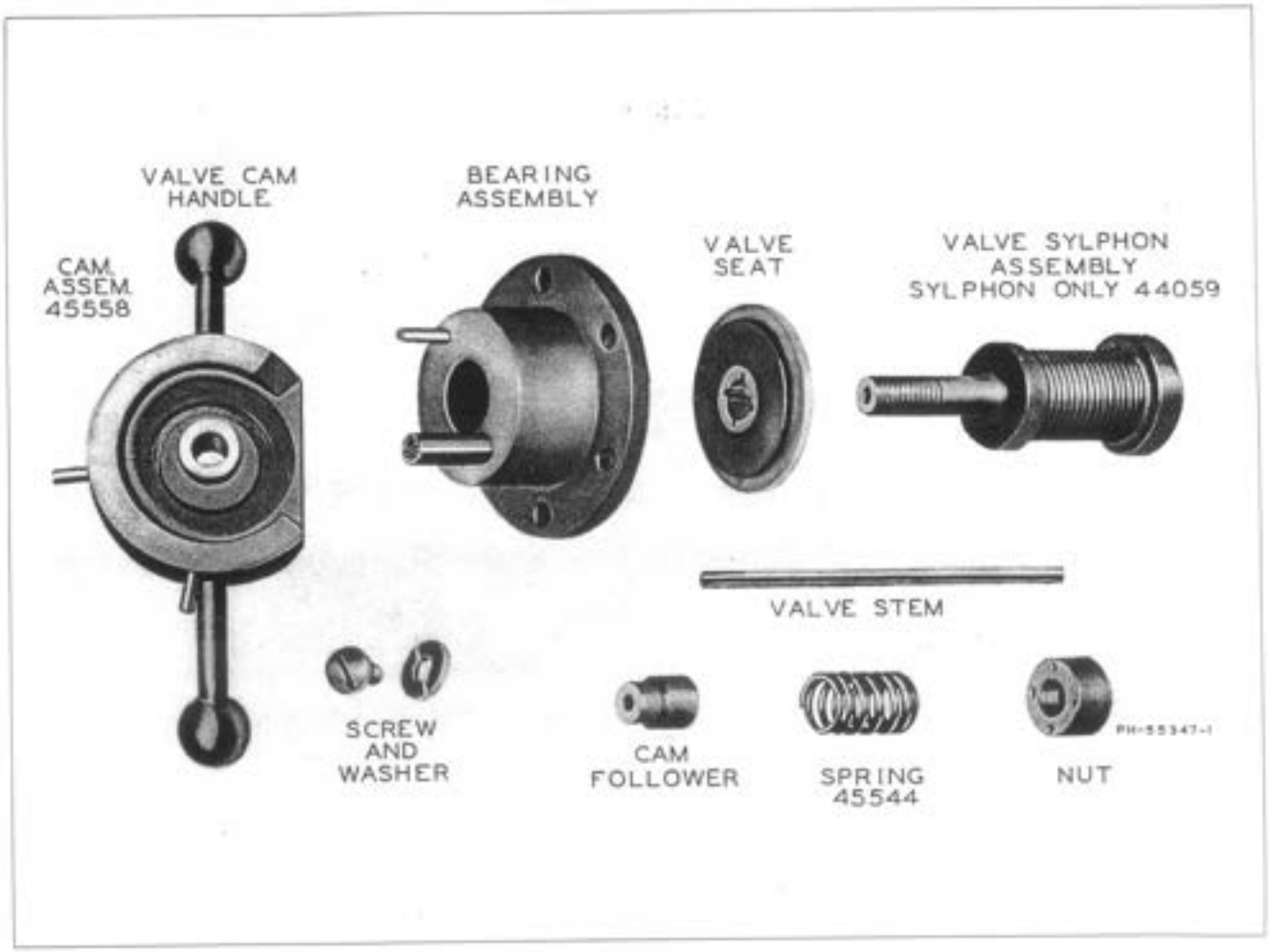

Figure 39—Photographic Chamber Valve Mechanism Details

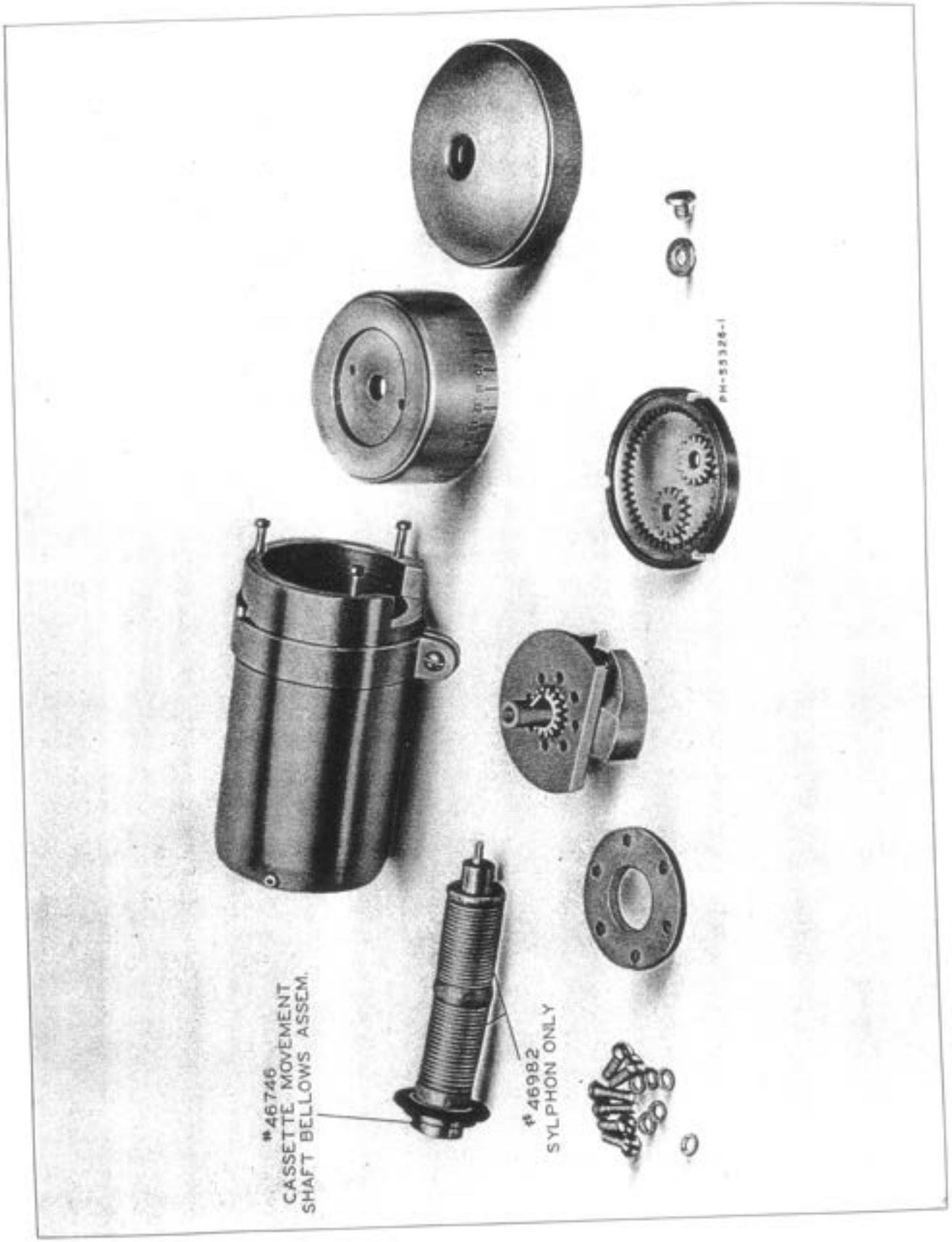

Figure 40—Photographic Chamber Control Knob Details

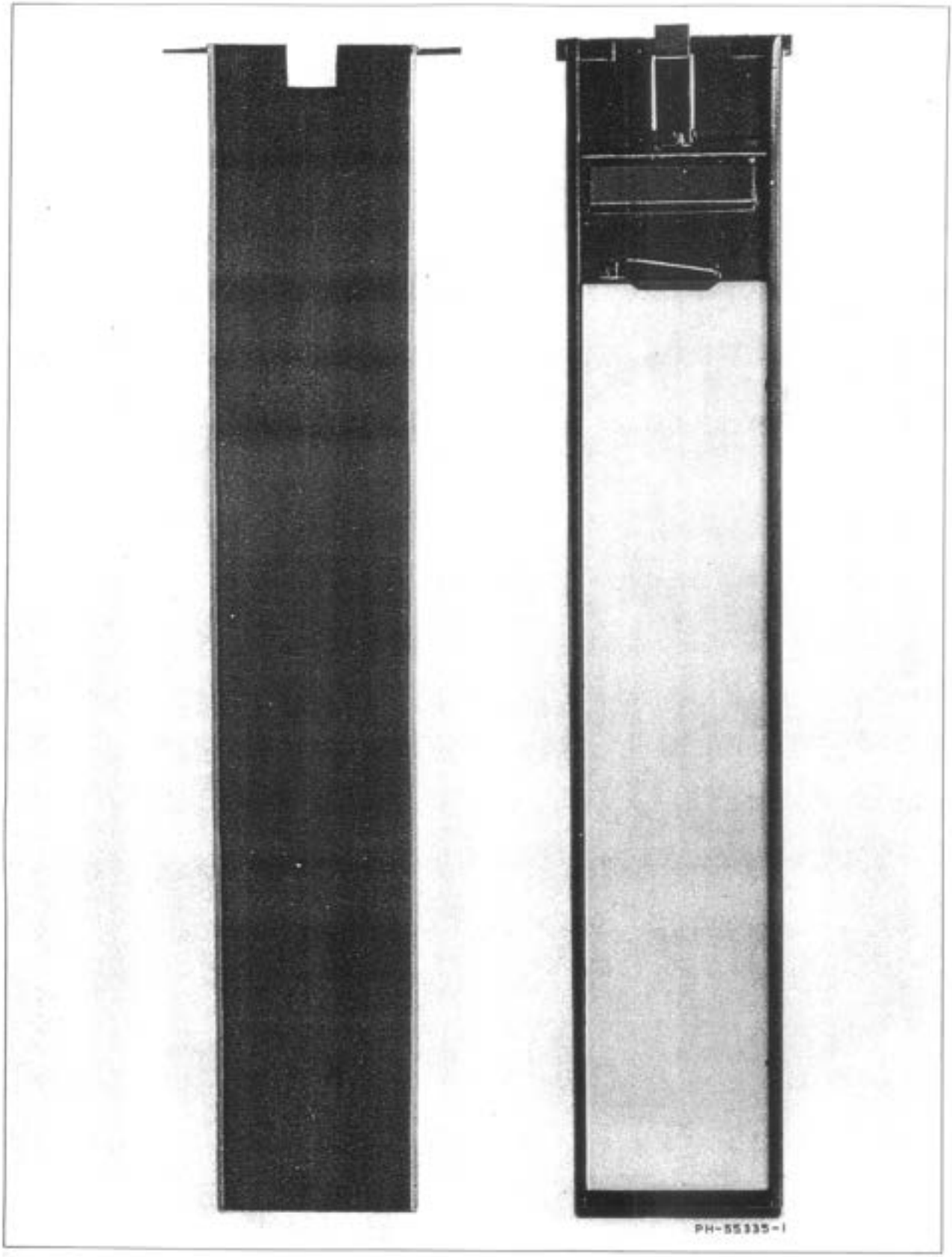

Figure 41—*Photographic Plate Cassette*

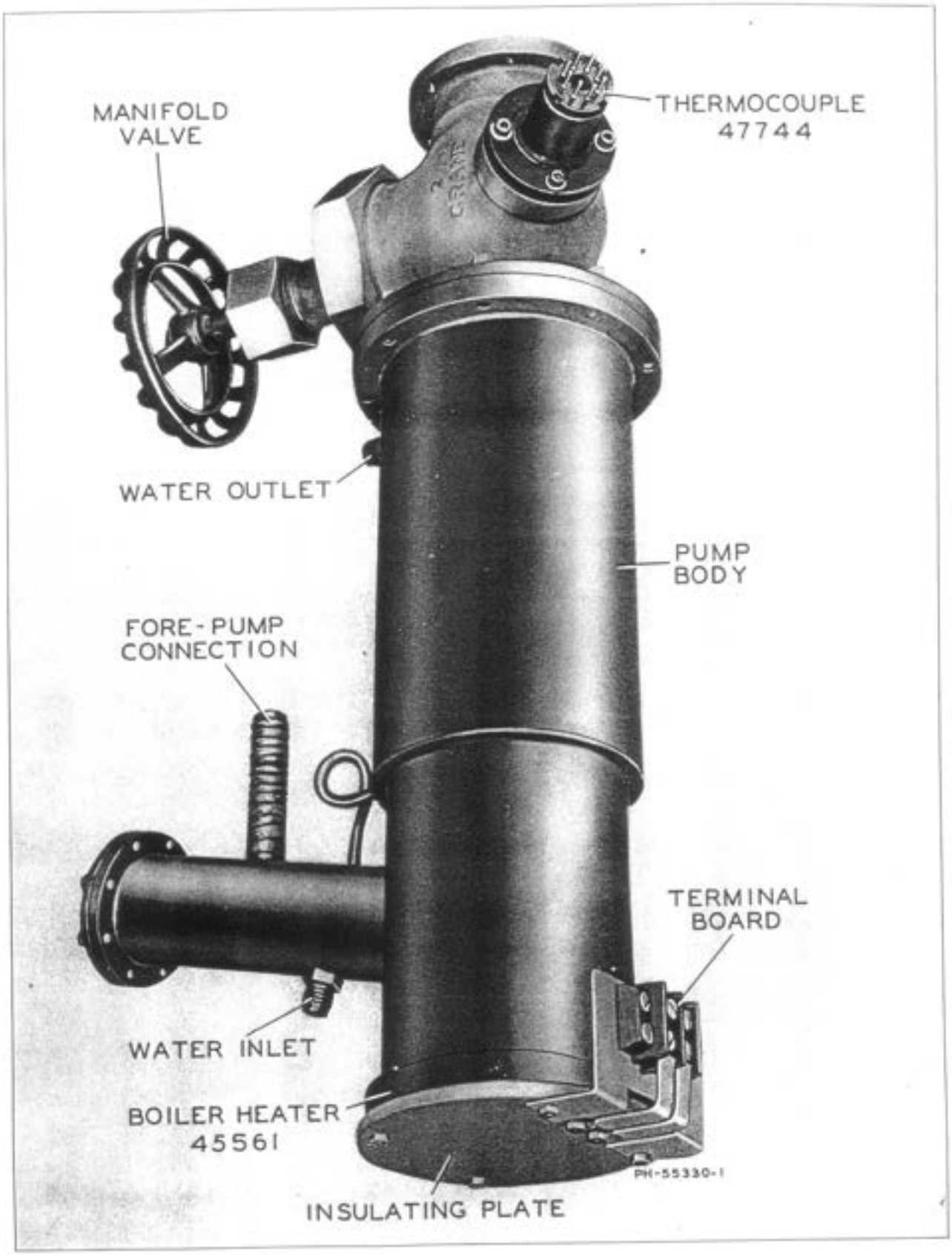

Figure 42—Diffusion Pump, Side View

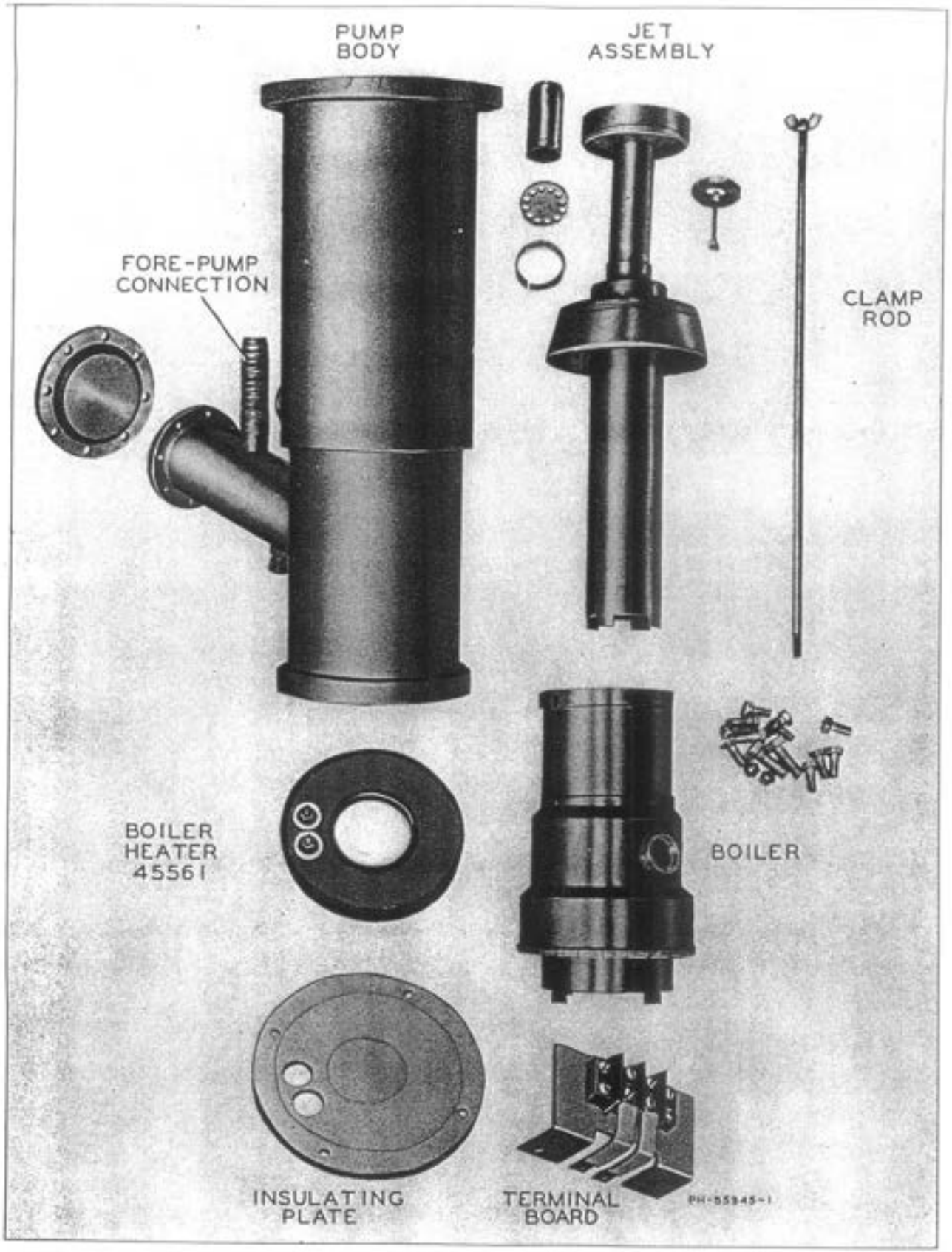

Figure 43—Diffusion Pump Details

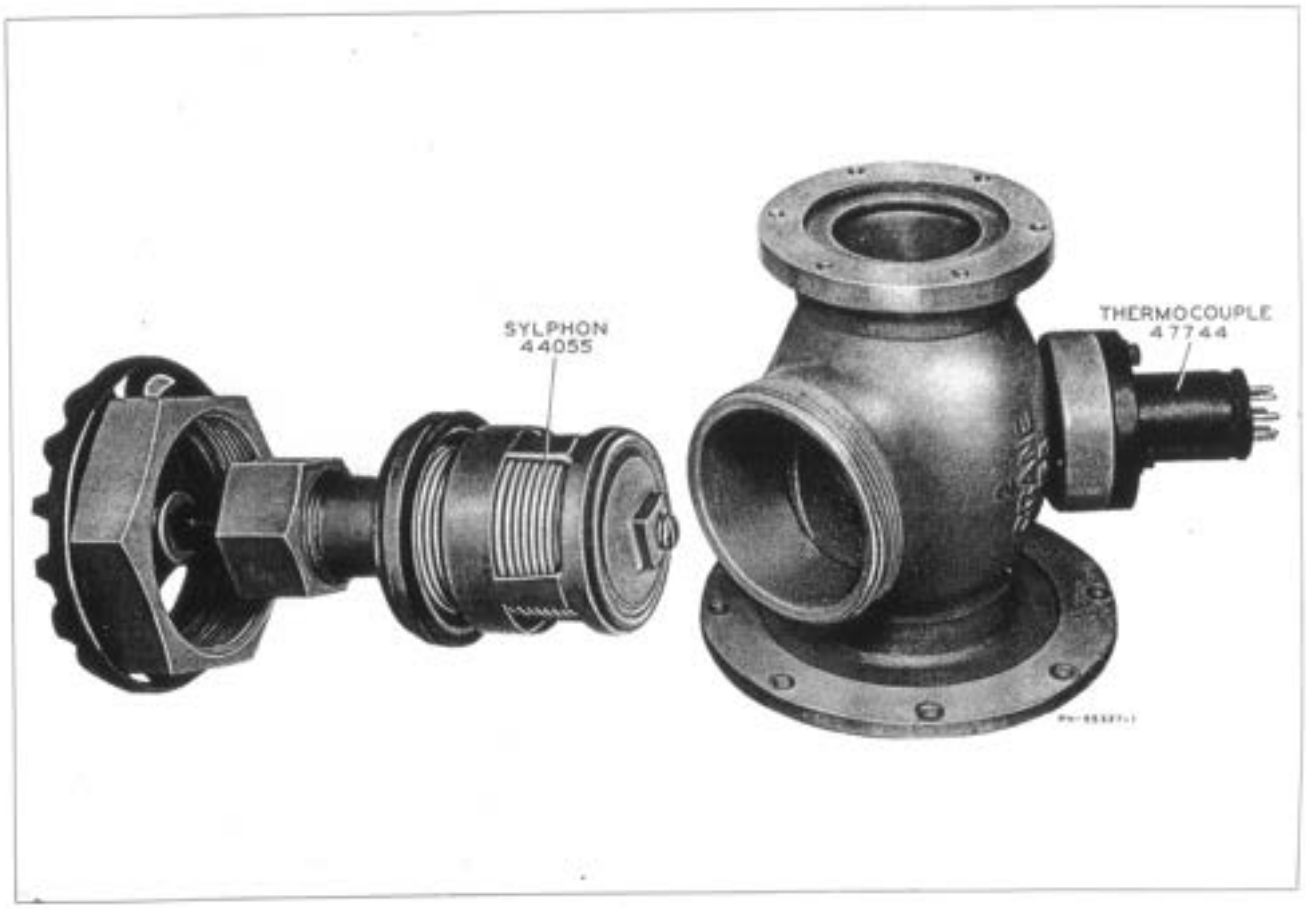

Figure 44—Diffusion Pump Valve and Thermocouple Gauge

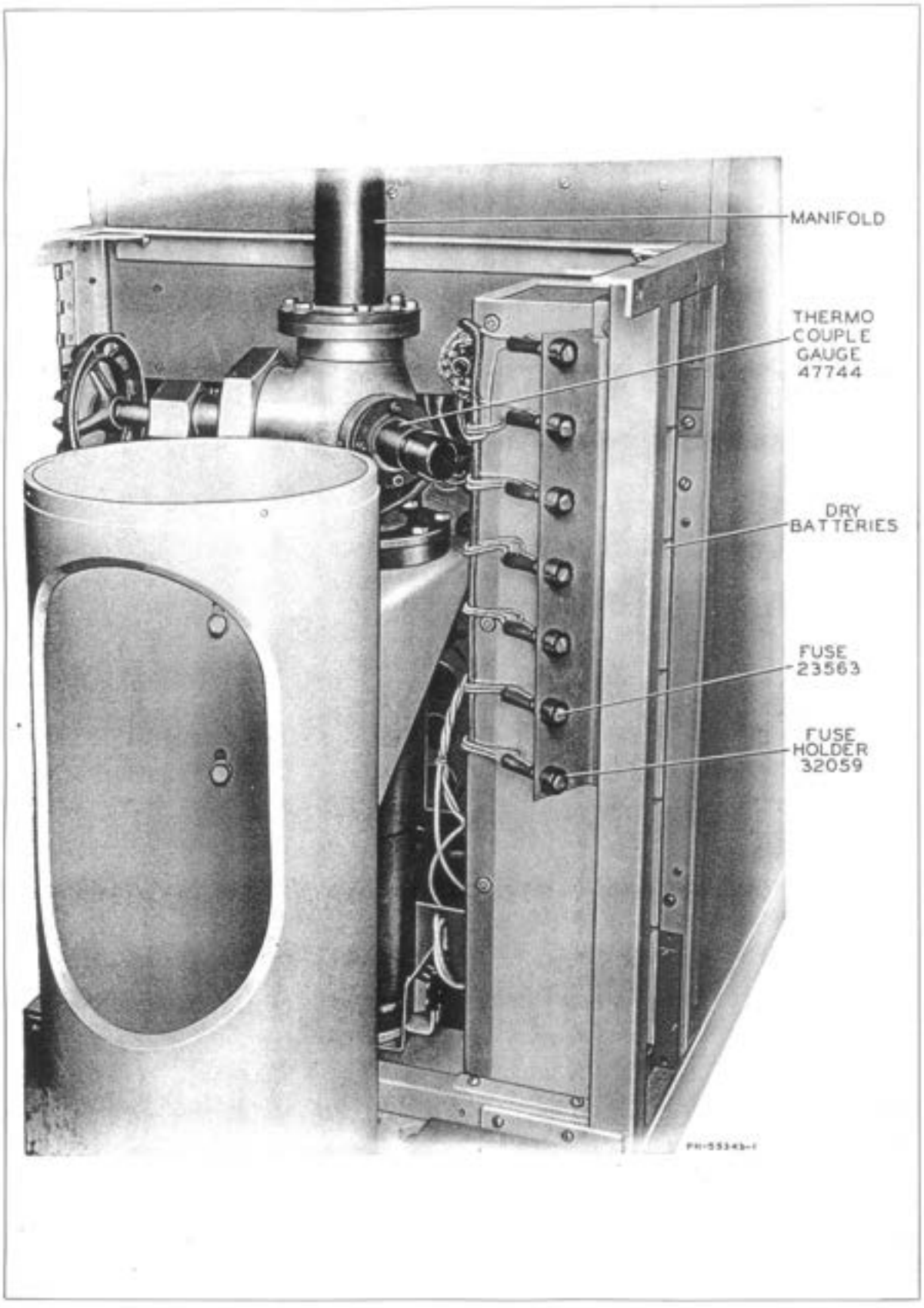

Figure 45—Casing, Lower Part, Right Front View

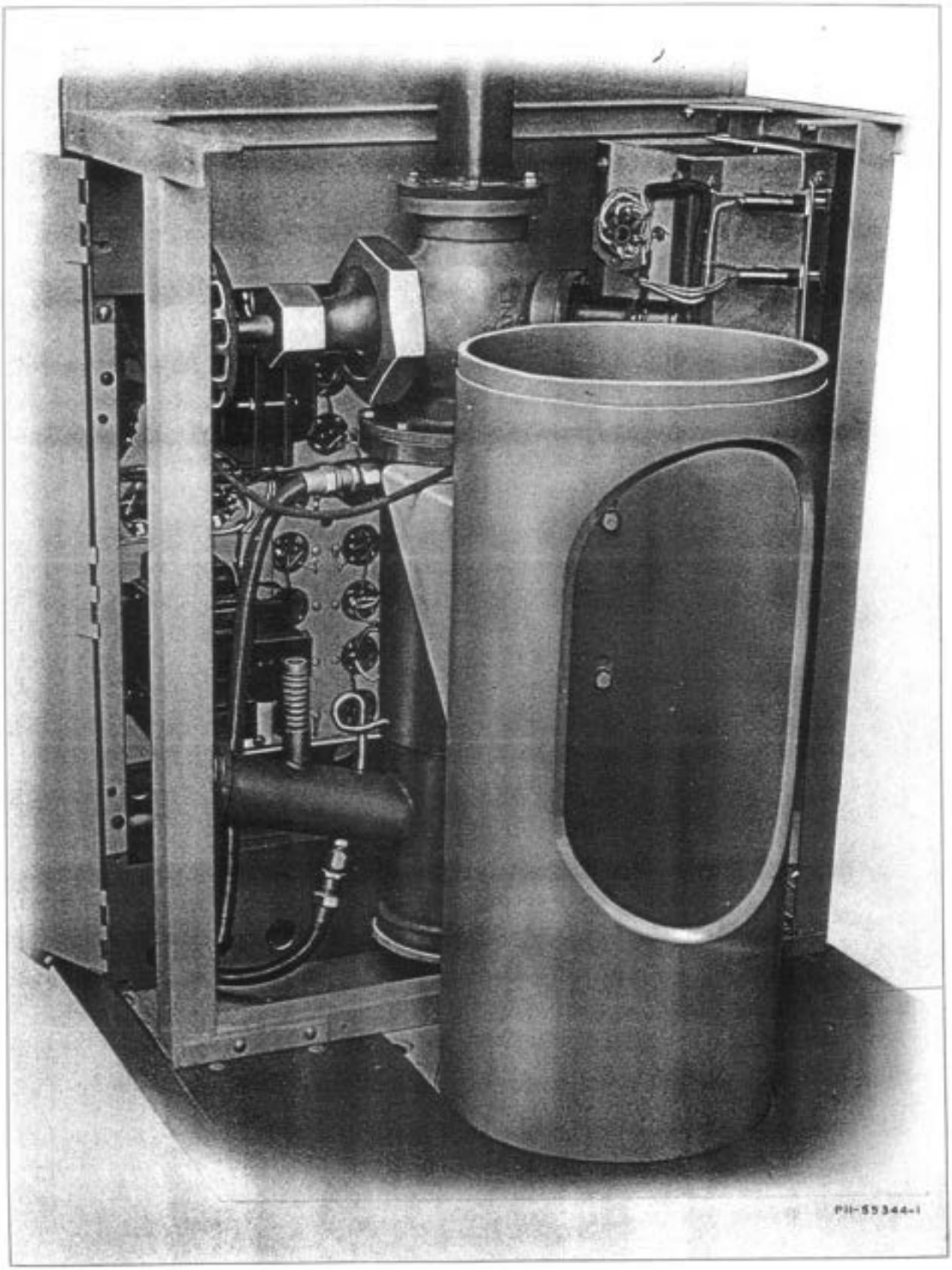

Figure 46—Casing, Lower Part, Left Front View

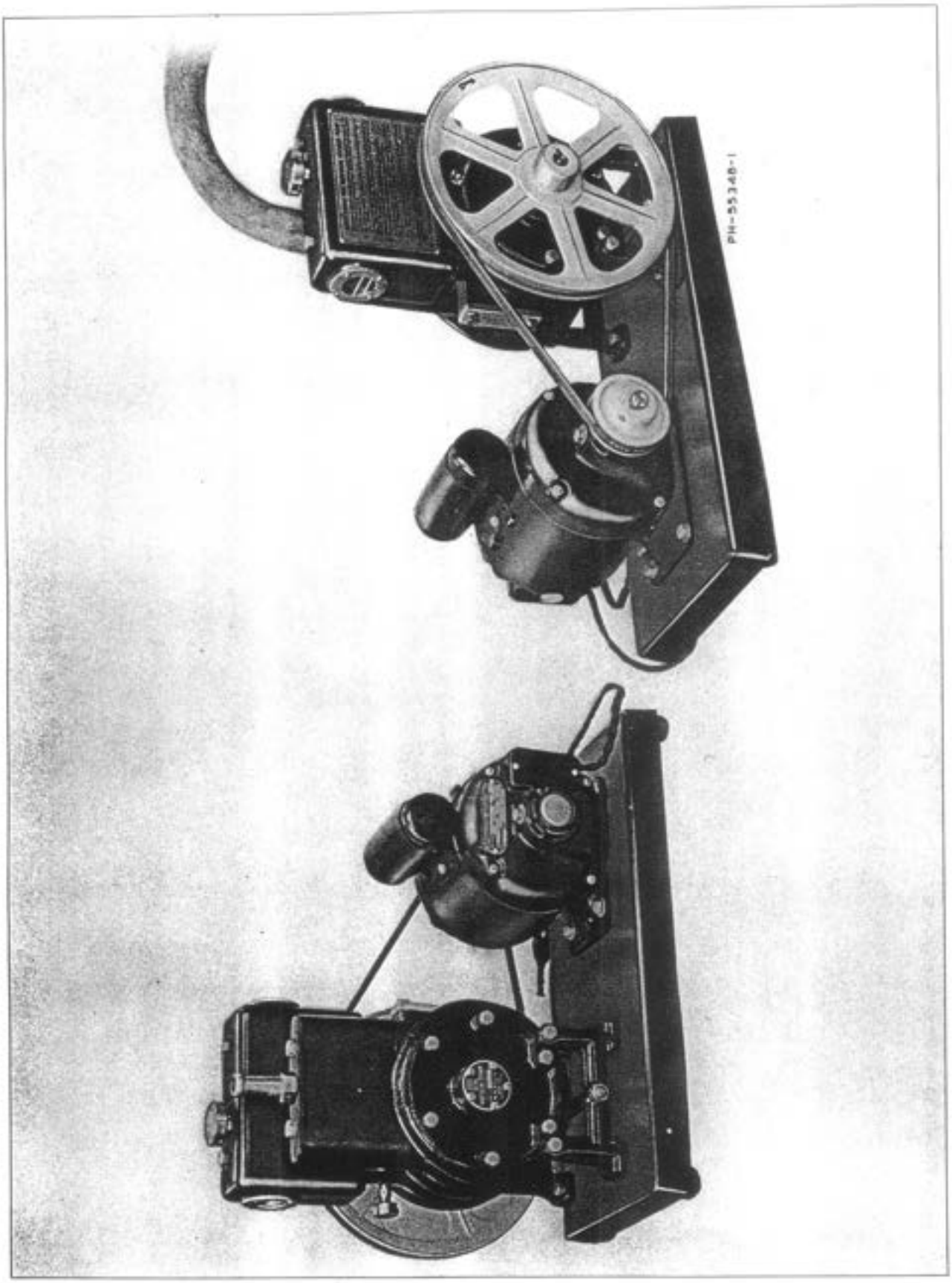

Figure 47—Rotary Pump, Front and Rear Views

Figure 48—Pole Pieces and Aperture Holders

Figure 49—Projector Pole Piece Details

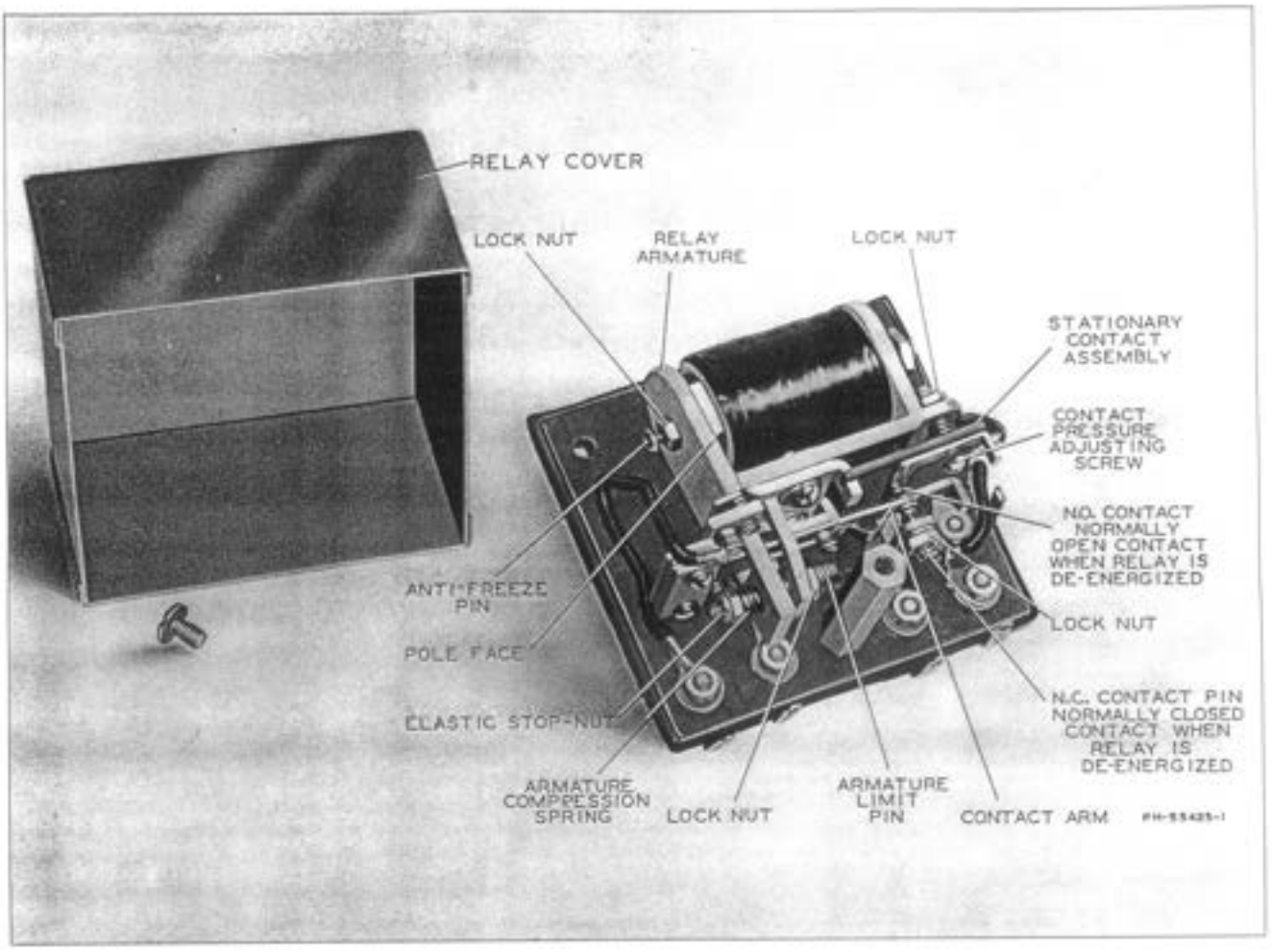

Figure 50—Overload Relay (Stock No. 47477)